HAI Model

Release 5.0a

Model Description

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1. Introduction

1.1. Overview

The HAI Model, Release 5.0a ("HM 5.0a") has been developed by HAI Consulting, Inc. ("HAI"), of Boulder, Colorado,[1] at the request of AT&T and MCI for the purpose of estimating the forward-looking economic costs of:

a) Basic local telephone service;

b) Unbundled network elements ("UNEs"); and

c) Carrier access to, and interconnection with, the local exchange network.

All three sets of costs are calculated based on Total Service Long Run Incremental Cost ("TSLRIC") principles, and use a consistent set of assumptions, procedures and input data.[2]

The HAI Model uses the definition of basic local telephone service adopted by the Federal-State Joint Board on Universal Service ("Joint Board") for universal service funding purposes. The Joint Board states that the following functional elements are to be considered as required components of universal service:[3]

- single-line, single-party access to the first point of switching in a local exchange network;
- usage within a local exchange area, including access to interexchange service;
- touch tone capability;
- access to 911 services, operator services, directory assistance, and telecommunications relay service for the hearing-impaired.

Excluded from this definition of universal service are many other local exchange company ("LEC") services, such as toll calling, custom calling and CLASS[SM] features,

[1] With its Release 5.0a, the model formerly known as the Hatfield Model is now named the HAI Model. Hatfield Associates, Inc., the firm that developed prior versions of the Hatfield/HAI Model no longer performs telecommunications consulting. All of the staff of Hatfield Associates who have played an active role in developing the Hatfield/HAI Model have formed a successor firm, called HAI Consulting, Inc.

[2] When applied to the costing of unbundled network elements, TSLRIC equates to Total Element Long Run Incremental Costs, or TELRIC as the term is used by the Federal Communications Commission.

[3] Federal-State Joint Board on Universal Service, CC Docket No. 96-45, Recommended Decision, November 8, 1996, ("Recommended Decision") Paragraph 45-53, 65-70.

private line services and white pages directory listings.[4] The existence of such services is taken into account in developing the cost estimates for UNEs -- to the extent that the joint provision of UNEs and other services impacts the costs of UNEs. Model users also may adjust the degree to which several specific UNEs are included in calculating universal service support requirements.

The HAI Model calculates the costs of the following UNEs:

- Network Interface Device ("NID")
- Loop Distribution
- Loop Concentrator/Multiplexer
- Loop Feeder
- End Office Switching
- Common Transport
- Dedicated Transport
- Direct Transport
- Tandem Switching
- Signaling Links
- Signal Transfer Point ("STP")
- Service Control Point ("SCP")
- Operator Systems
- Public Telephones

Finally, the model estimates the per-minute economic cost of providing local network interconnection and access. These are estimated for connection points at end office and tandem switches.

The model constructs a "bottom up" estimate of the pertinent costs based upon detailed data describing demand quantities, network component prices, operational costs, network operations costs, and other factors affecting the costs of providing local service. The model's demand data, particularly data describing customer locations, line demand, and traffic volumes, serve as the key initial drivers. From these data, the model engineers and costs a local exchange network with sufficient capacity to meet total demand, and to maintain a high level of service quality.[5] The model's inputs also include the prices of various network components, with their associated installation and placement costs, along with various capital cost parameters. These data are used to populate detailed input tables describing, for example, the cost per foot of various sizes of copper and fiber cable, cost per line of switching, cost of debt, and depreciation lives for each specific network component.

[4] Although previous versions of the Hatfield/HAI Model included the monthly cost of maintaining a white pages telephone listing for each subscriber, the Joint Board and FCC have explicitly excluded this item from the definition of supported universal service. Thus, in HM 5.0a its inclusion in cost calculations for basic service is only at the user's express direction.

[5] In general, the level of service quality engineered into the HAI Model exceeds, by a substantial margin, the customary level of basic service quality offered by the LECs over their embedded networks.

Using these data, the model calculates required network investments by detailed plant category. Next, the capital carrying cost of these investments is calculated. Operations expenses are then added to compute the total monthly cost of universal service, various unbundled network elements, stated on both a total cost and an appropriate per-unit basis, and carrier access to and interconnection with the local exchange network. Costs can then be displayed on a study area, density zone,[6] wire center, Census Block Group ("CBG"), or customer cluster basis.[7]

This document describes the structure and operation of the HM 5.0a, including a discussion of various inputs to the model. Section 1.2 describes the recent evolution of the Hatfield/HAI Model. Section 2 summarizes changes made to the model between HM 4.0 and this version. Section 3 provides a general overview of the local network being modeled. Section 4 reviews briefly the structure of the model and its data. Section 5 focuses on the method by which customer locations are determined and clustered. Section 6 describes in detail each module and its operation. Section 7 summarizes the document.

Appendix A provides a brief history of the Hatfield/HAI Model. Appendix B identifies the user inputs to the model and their default values. Appendix C provides flow charts describing the data input development process used to obtain demographic and geological information, residence and business line counts, wire center mappings and loop distances. Appendix D describes the HM 5.0a's calculation of interoffice network distances. Finally, Appendix E provides equation listings of the HM 5.0a's network engineering logic modules.

1.2. Evolution of the Hatfield/HAI Model

On May 7, 1997, the FCC released its Order implementing the mandate for universal service contained in the Telecommunications Act of 1996. In the Order, it declined, on the basis of its current record, including the Report of the State Members of the Joint Board, to endorse a model, and indicated it would issue a Further Notice of Proposed Rulemaking (FNPRM) detailing what it believed to be the appropriate requirements and guidelines that such a cost methodology should incorporate. This FNPRM was released on July 18, 1997. In this FNPRM the FCC provided a wealth of information about what the Commission believes are the appropriate properties to be incorporated into a proxy cost methodology. These include:

- A more sophisticated and precise method of locating customers;

[6] The HM 5.0a differentiates among density zones based on the number of subscriber access lines per square mile of service area.

[7] A CBG is a unit defined by the U.S. Bureau of the Census, and nominally comprises between 400 and 600 households. Customer clusters are dynamically formed aggregations ranging from singleton isolated customer locations, up to 1800 customer locations. See, Section 5.5 below, for a description of the spatial and size criteria used by the HM 5.0a in forming customer clusters.

- A choice of outside plant technologies and structures that reflects more closely local cost conditions;

- Explicit modeling of host/remote relationships between end office switches; and

- More flexible assignments of expenses based either on lines or relative investments.

The Commission set up a series of weekly meetings, and Comment and Reply cycles to address each of these and other related issues in greater depth. The Commission also indicated its intention to select a model for determining universal service support for nonrural carriers by the end of 1997.

HM 5.0a, as here submitted, is responsive to each the Commission's requirements as presented in the Order, the requirements outlined in the FNPRM on cost modeling, and the public notice guidance provided by the Commission subsequent to its release of the FNPRM. Indeed, HM 5.0a represents a revolutionary advance in the modeling of local telephone network costs by its incorporation of:

- Actual gecoded customer locations;

- An algorithm that identifies clusters of customers that may be served efficiently together – without recourse to arbitrary geographic limitations;

- Numerous optimization routines that ensure the use of outside plant that is most technically and economically suited to particular local conditions;

- Explicit specification of host, remote and stand-alone switches;

- An optimizing algorithm for the creation of efficient interoffice SONET transport rings; and

- Opportunities to allocate flexibly expenses based on lines or relative investments.

As a result of these many changes, HM 5.0a has refined greatly the task of identifying actual customer locations, and clustering them into units logically served by telecommunications outside plant. The model has thus moved well ahead of other models that employ more geographically limited, rule-of-thumb calculation techniques.

HM 5.0 was originally submitted to the FCC on December 11, 1997. A number of small but significant changes have been made to the Model's data, logic and documentation since that time. These are incorporated into a revision referred to as HM 5.0a, released January 28, 1998. Section 2.8 summarizes the changes between HM 5.0 and HM 5.0a. To the extent those changes impact the model description, they are reflected in this document.

2. Summary of Changes Between HM 4.0 and HM 5.0

The changes between HM 5.0 and the previous release of the model, HM 4.0, are summarized in the first portions of this section. Section 2.8 summarizes the changes between HM 5.0 and HM 5.0a. All of these changes are reflected in the discussion of how HM 5.0a operates, presented in Sections 4 and 6.

2.1. User Interface

- The new features of the user interface provide the user with many additional inputs and options. Among the new inputs included are the ability to designate specific end office switches as hosts, remotes, or standalones – as well as to assign remotes to a particular host; ability to specify variable T1 repeater spacing; ability to enable the steering of feeder toward population clusters within a quadrant; the ability to invoke a wireless distribution option if its cost is less than wireline, and many more.

- The interface also now allows the user to select multiple companies from one or more states (limited only by hard drive space) to be run in automatic sequence by the model. Expense Modules and workfiles are then produced for each individual company, and their universal service calculations rolled up.

2.2. Input Data

- The HM 5.0a input data locate customers much more precisely. These data determine the actual precise locations of as many customers as possible through latitude and longitude geocoding of their addresses. The remainder are located to at least the Census Block ("CB") level of precision and are assumed to be placed along the CB's periphery.[8]

- A clustering algorithm is used to determine groupings of customers that have extremely realistic correlation to efficient distribution areas.

- The August 1997 Local Exchange Routing Guide ("LERG") is used to identify and locate LEC wire centers.

- Business Location Research ("BLR") wire center boundaries are used to associate customer locations with LEC wire centers. This ensures that all identified clusters

[8] Previous versions of the HM only located customers precisely to their Census Block Group (CBG). Within high density CBGs, customers were assumed either to be spread uniformly across the CBG. In low density CBGs, a portion of customers was assumed to be clustered in quadrants, while another portion was assumed to spread along outlying roads.

are restricted to include only customer locations that fall within the boundaries of a single wire center.

- Company line count totals are determined from the most recent available data, including that provided in the 1996 ARMIS data and NECA USF Loops filing for 1996.

- The method of estimating line counts by LEC wire center is refined, and line counts can be determined by CB.

- 1996 ARMIS data (rather than 1995 ARMIS data) are used to estimate traffic volumes and expense inputs.

2.3. Outside Plant Selection

- HM 5.0a automatically adjusts buried and aerial structure fractions to account for varying maintenance costs and placement costs occasioned by local soil conditions and bedrock. The amount of one type of structure substituted for another depends both on differences in placement costs and on a life-cycle analysis of maintenance and capital carrying costs of the two types of structure.

2.4. Distribution Module

- HM 5.0a lays its distribution plant directly over the actual identified locations of customer clusters.

- Rather than assuming that the distribution area is square, HM 5.0a engineers its distribution grid as a rectangle. The aspect ratio (height-to-width) of this rectangle is determined by the data input development process for each cluster, and distribution cable is laid out in a fashion that reflects this aspect ratio.

- HM 5.0a serves “outlier” clusters from “main clusters” on which they home, using digital T1 technology whenever the road cable length exceeds a user-adjustable maximum analog copper distance.[9] The cables carrying T1 signals to the outlier clusters are separate from the analog copper cables that extend from the T1 terminal in each outlier cluster to the customer locations within the outlier cluster.

- Assuming that the distance of a cable run is sufficiently short so that use of copper feeder is a technically acceptable option, the HM 5.0a performs an analysis of the relative life-cycle costs of copper versus fiber feeder to determine which feeder technology should be used to serve the given main cluster.

[9] Outlier clusters are clusters that contain fewer than five lines. Main clusters are cluster containing five or more lines. These clusters are served by feeder linking them to their serving wire center. See Section 6.3.2 for more detail.

- The HM 5.0a also incorporates an optional, user-adjustable "cap" on distribution investment. This cap is structured to reflect the potential cost structure of wireless distribution technologies.

2.5. Feeder Module

- HM 5.0a engineers feeder to serve actual population main clusters (and uses distribution cable to serve main clusters' subtending outlier clusters), rather than simply engineering to each CBG.

- At the user's option, the HM 5.0a "steers" feeder routes toward the preponderant location of main clusters within a given wire center quadrant.[10] When this steering is invoked, the user may also apply an adjustable route-to-airline distance multiplier to the amounts of cable placed along these "steered" feeder routes.

- Manhole placement costs are increased by a user-specified amount whenever the local water table depth is less than the user-specified threshold.

2.6. Switching and Interoffice Module

- At the user's discretion, HM 5.0a will both engineer and cost explicit combinations of host, remote and stand-alone end office switches. If the user does not make such a specification, the HM 5.0a defaults to computing end office switching investments using input values that provide average per-line investments for an efficient portfolio of host, remote, and stand-alone switches.[11] If the host/remote/standalone designation option is invoked, the user is required to specify whether a wire center houses switches that are hosts or remotes, as well as to assign the correspondence between host and remote switches.

- Further, when the user chooses the model to distinguish explicitly between switch types, the HM 5.0a assumes that each host and its remotes are on a Synchronous Optical Network ("SONET") fiber optics ring separate from the interoffice rings used to interconnect host, standalone and tandem switches with each other.

- The HM 5.0a calculates explicitly a set of interoffice SONET rings that interconnect host, standalone, and tandem switches with each other. Based on this explicit specification of what wire centers are on each interoffice ring, the HM 5.0a determines associated ring distances using the actual locations of the wire centers along the ring. In addition, the rings are appropriately interconnected

[10] The default treatment, if steering is not invoked, is for the Feeder Module to calculate feeder distances using "right angle routing" in the four cardinal compass point directions, as employed in HM 4.0.

[11] The Model defaults to an average per-line mix because accurate data on the purchase prices of a portfolio of host, remote and standalone switches of varying capacities, and on the identification of hosts, remotes, and stand-alone switches, may not be available to the user.

with each other, and tandem switches are also interconnected if they fall within the same LATA.[12].

- The HM 5.0a engineers redundant paths and associated transmission terminal equipment for the point-to-point (folded) rings that may be specified to connect small offices to the larger wire centers on which they home.[13]

2.7. Expense Modules

- A Uniform System of Accounts ("USOA") detail worksheet is included that breaks out HM 5.0a investments and expenses by Part 32 account for comparison purposes.

- The proportion of total expenses that are assigned to loop network elements (i.e., NID, distribution, concentration and feeder) can be varied based either on relative number of lines, or on the relative amount of direct expenses (direct expenses include both maintenance expenses and capital carrying costs for the specific network elements).

- Both federal and state universal service fund requirements can be calculated in the density zone USF worksheet. This separate calculation permits differing state and federal cost benchmarks to be specified, as well as different collections of local services (e.g., primary and secondary residential lines, single business lines, etc.) to receive universal service support.

- In addition to displays of costs at the lines density zone and wire centers levels of aggregation, costs can also be displayed at the CBG and individual population cluster level.

2.8. Changes Incorporated in HM 5.0a

2.8.1. Distribution Module

- HM 5.0a modifies its method of dividing clusters to more efficiently ensure that the length of cables carrying analog signals never exceeds the user-set maximum (default = 18,000 ft).

- HM 5.0a corrects minor typographical errors in equations used to calculate the portions of structure that "swing" between buried and aerial based on abnormal local life-cycle costs, and in the wireless cap equations.

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[12] InterLATA links are excluded from the model because such links are not part of the local exchange network.

[13] The user may specify a minimum number of lines that a wire center must serve (default of just one) before that wire center is placed on an interoffice ring with other end office switches – rather than being interconnected directly only to its "home" wire center.

- Adds columns that calculate average loop lengths.

2.8.2. Switching and Interoffice Module

- The time required to execute this module for large companies is reduced by sourcing from other portions of the workbook, rather than calculating, certain distance and DS3 count information.

- For wire centers owned by small LECs without local tandems, connectivity to a tandem is established in two pieces. First, a spur is engineered to the closest large LEC wire center that is on an interoffice ring. Second, the equivalent investments in facilities and terminal equipment associated with the required number of leased circuits on this ring that are used to connect this large LEC wire center to its tandem are calculated on a per-DS0 facilities basis. This is in contrast to the previous method of determining the cost of interoffice route between the Large LEC wire center and its tandem based on multiplying the distance between these nodes by an assumed dedicated circuit-mile charge.

- Rings now must have a minimum of four nodes, assuming there are that many wire centers, versus a prior minimum of two nodes.

- HM 5.0a provides several new "traps" to prevent certain execution problems. These include: 1) the ring-generating code is modified to expect the user-specified "host/remote enable" option as boolean type rather than a string; 2) stand-alone tandems now have an associated interoffice distance; 3) the number of allowed wire center records has been increased from 1,500 to 2,000; 4) the ring-generating code contains logic to determine whether host/remote calculations are enabled before eliminating remotes as first order ring candidates; 5) the ring-generating code uses wire center records generated from the HM5.0a database as the source of the locations associated with a particular state and operating company; 6) the ring-generating code now updates the progress bar in closer proportion to the module's degree of completion; 7) the ring-generating code writes all results into a list in the "ring io" worksheet; 8) the array dimension in the routine computing interoffice mesh distances has been increased from 25 to 100 elements; and 9) several additional "divide checks" are provided and syntax errors corrected.

2.8.3. Expense Modules

2.8.3.1. Density Zone and Wire Center Versions

- Corrects the calculation of weighted average depreciation life for non-metallic cable to include interoffice fiber facilities.

- The "Cost detail" sheet of the DZ version allows for the substitution of ICO-equivalent DS0 transport values.

- Corrects cell references for residential and business usage in the wire center USF sheet from absolute to relative.

2.8.3.2. Expense Modules – CBG and Cluster Versions

- Improves on the previous CBG expense module by associating cluster costs to the several CBGs that may overlay the cluster in proportion to the relative number of lines that each CBG displaces of the cluster's total quantity of lines.

- Adds a Cluster expense module that displays cost results on a customer cluster-by-cluster basis.

2.8.4. Interface Items

- Corrects several non-functioning items in the interface, including: 1) permitting Puerto Rico to be run through the interface; 2) fixing the OLE error that previously has occurred the initial time the newly installed HM 5.0 is run; and 3) speeding the run time of the Feeder module

2.8.5. Input Data Items

- Corrects several data discrepancies, including: 1) correcting the several "problem clusters" that previously were incorrectly sized; 2) adding the clusters that were missing from the California data; and 3) assigning correctly the lines density classification of Puerto Rico clusters; and 4) correcting the state assignment of several small LECs that operate across state borders.

- Adds CBGMulti data table that relates clusters to the several CBGs that overlay them based on relative counts of lines associated with each CBG.

- Adds data that permit easy calculation of average loop lengths by cluster and wire center.

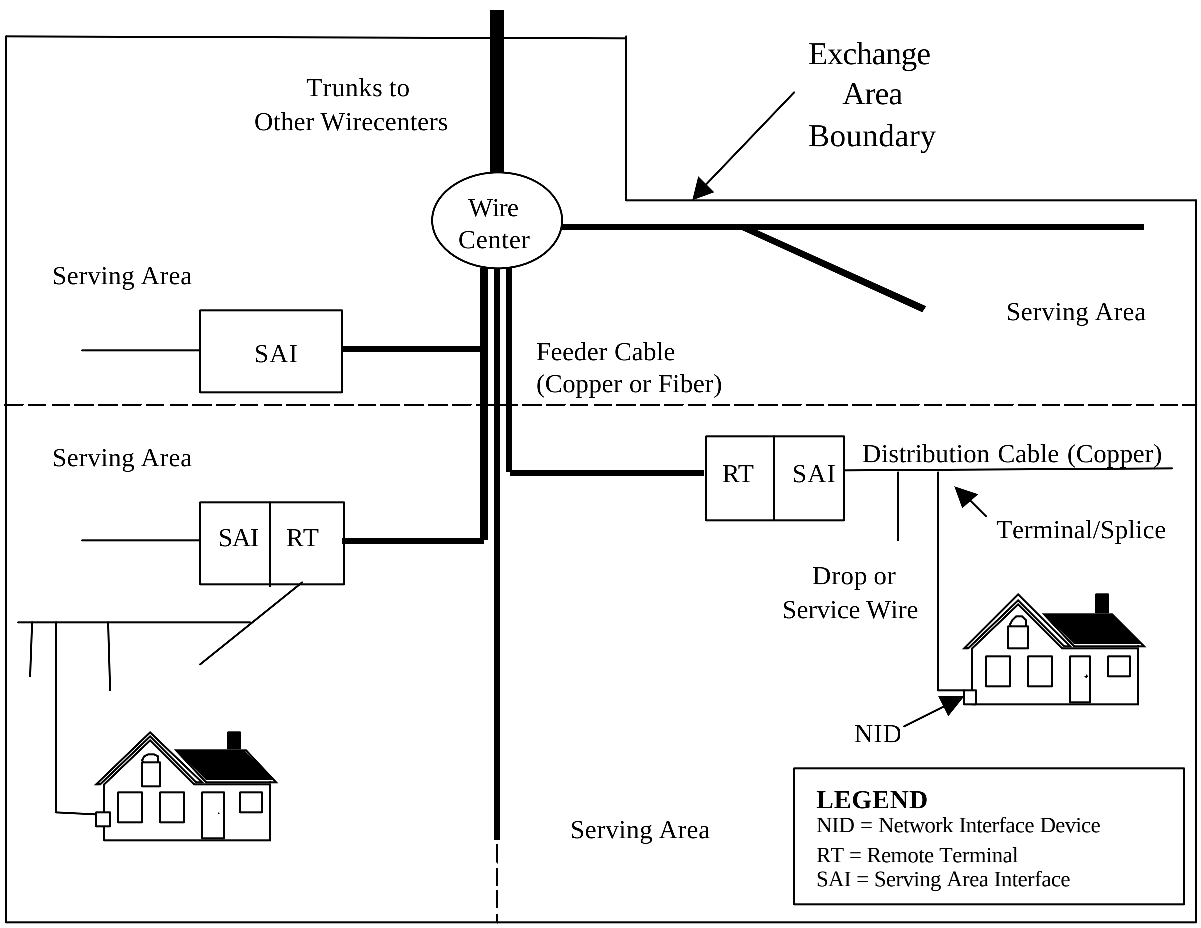
3. Fundamental Structure of Local Network

3.1. Components of the Local Exchange Network

This section describes the network configuration and components modeled in HM 5.0a. Figures 1, 2 and 3 depict the relationships among the loop, switching, interoffice, and signaling network components.

3.1.1. Loop Description

Figure 1 depicts the loop model utilized in HM 5.0a. Section 3.1.1.1 defines the serving area. Section 3.1.1.2 provides a general description of the loop, depicted in Figure 1. Section 3.1.1.3 describes the loop components in more detail.



Adapted from Engineering and Operations in the Bell System, 2nd Edition, 1983

Figure 1 Loop Components

3.1.1.1. Serving Area

The total area served by a wire center is organized into one or more serving areas, each of which contains a portion of the area and lines served by the wire center. The serving areas are delineated by dotted lines in the above figure. In HM 5.0a the serving areas equate to main customer clusters and their subtending outlier clusters, as discussed in Section 6.2.

3.1.1.2. General Loop Description

One end of the feeder portion of the loop terminates within the central office building, or "wire center." Copper cable feeder facilities terminate on the "vertical side" of the main distributing frame ("MDF") in the wire center, and fiber optic feeder cable serving integrated digital loop carrier ("IDLC") systems terminates on a fiber distribution frame in the wire center.

The other end of the feeder extends to an appropriate termination point in the serving area. Copper feeder cables terminate on one or more serving area interfaces ("SAIs") in each serving area, where they are cross-connected to copper distribution cables. Fiber feeder cables extend to a digital loop carrier ("DLC") remote terminal ("RT") in the serving area, where optical digital signals are demultiplexed and converted to analog signals. Individual circuits from the DLC are cross-connected to copper distribution cables at an adjacent SAI.

Copper distribution cable extends from the SAI along routes passing individual customer premises. At appropriate points, these cables pass through block terminals typically serving several housing units. In the terminal, individual copper pairs in the distribution cable are spliced to "drops" that extend from the terminal to the customers premises. The drop terminates at a network interface device, or NID, at the customer's premises.

Feeder, distribution, and drop cables are supported by "structures." These structures may be underground conduit, poles, or trenches for buried cable and underground conduit. Underground cable is distinguished from buried cable in that underground cable is placed in conduit, while buried cable comes into direct contact with soil.[14] In more urban areas, aerial distribution cable may be attached directly to the outside of buildings, in what is called a "block cable" arrangement, or, for high-rise buildings, may consist of riser cable inside the building.

3.1.1.3. Local Loop Components

1) *Network Interface Device*

   The NID is the demarcation point between the local carrier's network and the customer's inside wiring. This device terminates the drop wire and is an access point that may be used to isolate trouble between the carrier's network and the customer's premises wiring. The NID also contains protection against externally-

[14] Although the conduit supporting underground cable is always placed in a trench, buried cable may either be placed in a trench or be directly plowed into the earth.

induced hazardous voltages, such as those associated with lightning strikes and contact between telephone and electric lines. In a multi-tenant building, the protection is located at the point at which the distribution cable enters the building.

2) *Drop*

A copper drop cable, typically containing several wire pairs, extends from the NID at the customer's premises to the block terminal at the distribution cable that runs along the street or the lot line. The drop can be aerial or buried; generally it is aerial if the distribution cable is aerial, and buried if the distribution cable is buried or underground.

3) *Block Terminal*

The "block terminal" is the interface between the drop and the distribution cable. When aerial distribution cable is used, the block terminal is attached to a pole in the subscriber's front yard at the edge of a road. A pedestal contains the block terminal when distribution cable is buried.

4) *Distribution Cable*

Distribution cable runs between the block terminals and an SAI located in the serving area. Limitations on the capacity of an SAI and/or the distribution design used in a particular serving area may lead to multiple SAIs. Distribution structure components may consist of poles, trenches and conduit.[15]

5) *Conduit and Feeder Facilities*

Feeder facilities constitute the transmission system between the SAI and the wire center. These facilities may consist of either pairs of copper wire or a DLC system that uses optical fiber cables as the transmission medium. In a DLC system, the analog signals for multiple individual lines are converted to a digital format and multiplexed into a composite digital bit stream for transmission over the feeder facilities

Feeder structure components include poles, trenches and conduit. Manholes for copper feeder or pullboxes for fiber feeder are also normally installed in conjunction with underground feeder cable. Manhole spacing is a function of population density and the type of feeder cable used. Pullboxes that are installed for underground fiber cable are normally farther apart than manholes used with copper cables, because the lightness and flexibility of fiber cable permits it to be pulled over longer distances than copper cable.

[15] Because underground distribution exists only in the highest density zones where runs are relatively short, and because in such zones underground structure is commonly shared with feeder, distribution facilities typically do not include manholes.

Several utilities, e.g., electric utilities, LECs, IXCs and cable television ("CATV") operators, typically share structure because it is economical to do so. Manholes may be shared with low-voltage facilities. The amount of sharing of structure and manholes may differ in different density zones and between feeder and distribution cables.

3.1.2. Switching and Interoffice Network Description

This section provides a general description of the network components comprising the wire center and interoffice facilities. Figures 2 and 3 illustrate the relationships among the components described below.

3.1.2.1. Wire Centers

The wire center is a location from which feeder routes extend towards customer premises and from which interoffice circuits or "trunks" emanate toward other wire centers. A wire center normally contains at least one end office ("EO") switch and may also contain a tandem switch, an STP, an operator tandem, or some combination of these facilities. Wire center physical facilities include a building, power and air conditioning systems, rooms housing different switches, transmission equipment, distributing frames and entrance vaults for interoffice and loop feeder cables.

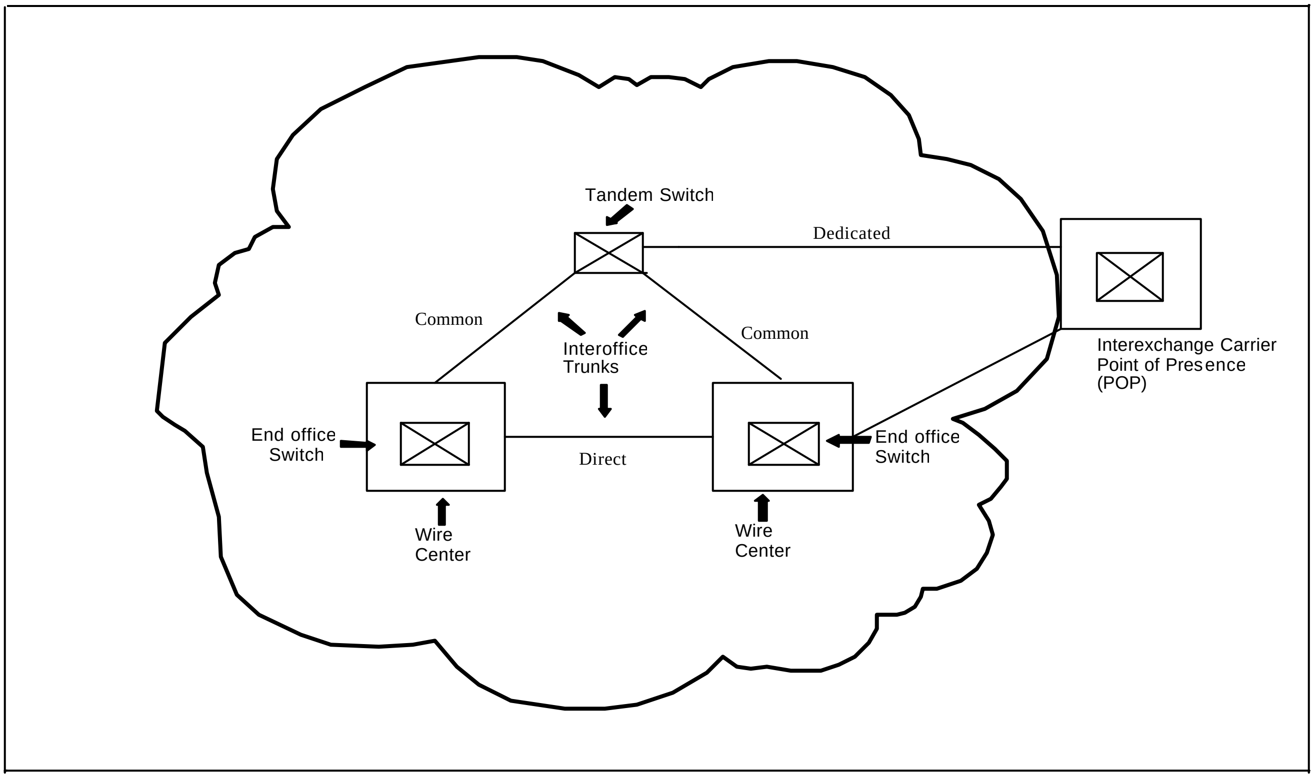


Figure 2 Interoffice Network

3.1.2.2. End Office Switches

The end office switch provides dial tone to the switched access lines it serves. It also provides on-demand connections to other end offices via direct trunks, to tandem switches via common trunks, to interexchange carrier ("IXC") points of presence ("POPs") via dedicated trunks, and to operator tandems via operator trunks.

3.1.2.3. Tandem Switches

Tandem switches interconnect end office switches via common trunks, and may also provide connections to IXC POPs via dedicated trunks. Common trunks also provide alternatives to direct routes for traffic between end offices. Tandem switching functions often are performed by switches that also perform end office functions. Tandems normally are located in wire centers that also house end office switches

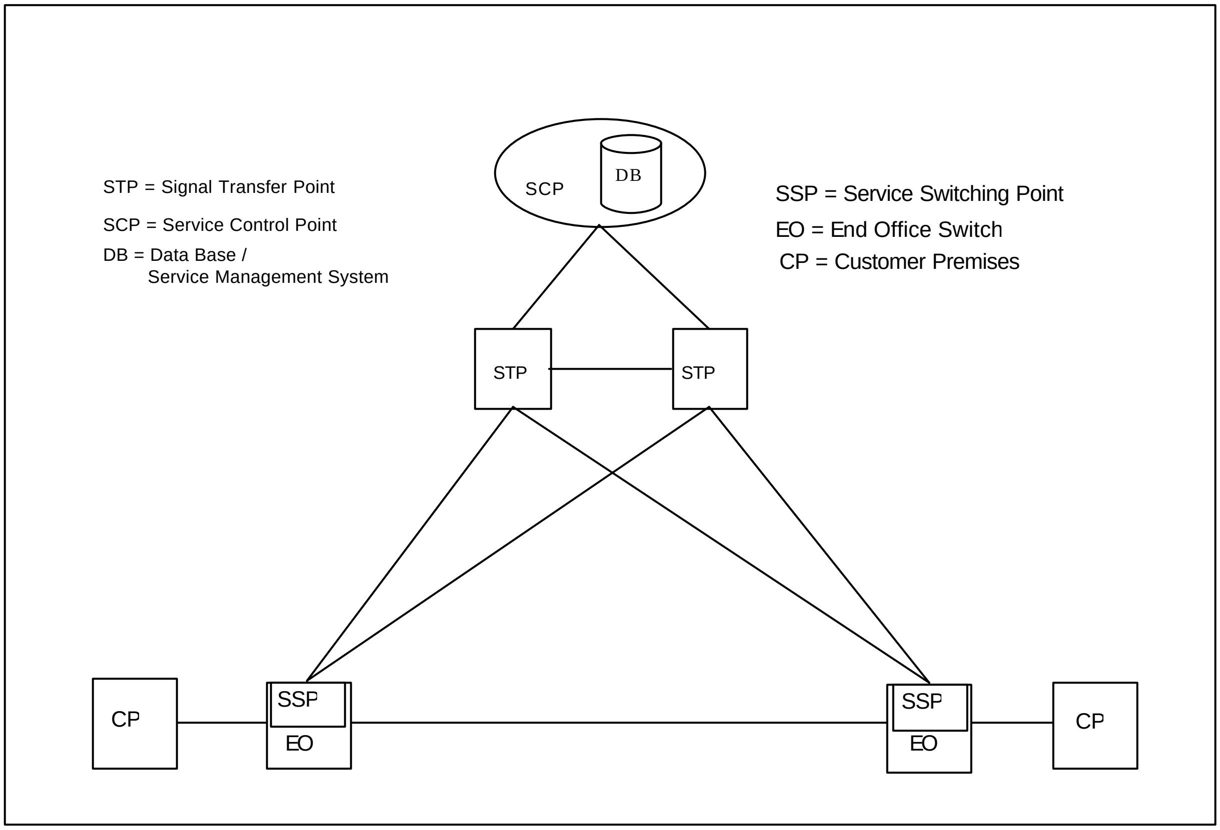


Figure 3 Interoffice Signaling Network Components

3.1.2.4. Interoffice Transmission Facilities

Interoffice transmission facilities carry the trunks that connect end offices to each other and to tandem switches. The signaling links in a Signaling System 7 ("SS7") signaling network are also normally carried over these interoffice facilities.

Interoffice transmission facilities are predominantly optical fiber systems that carry signals in SONET format. Both economic and service quality considerations increasingly prescribe the use of a fiber optic ring configuration to link switches, except for switches that serve few lines or that are too remote from other switches, where ring costs might be prohibitive. In this case, the small switches are typically connected to a nearby wire center housing another end office switch that is on a ring, or the tandem on which the small switch homes, via point-to-point links that are increasingly provided on a route-diverse (that is, redundant) basis for the sake of increasing reliability. Use of rings and redundant point-to-point links in this fashion provides an extremely secure path between any two switches, and the potential for substantial cost savings relative to the ubiquitous deployment of traditional point-to-point facilities interconnecting all switches.

3.1.2.5. Signal Transfer Points

STPs route signaling messages between switching and control entities in a SS7 network. Signaling links connect STPs and Service Switching Points ("SSPs"). STPs are equipped in mated pairs, with at least one pair in each Local Access Transport Area ("LATA").

3.1.2.6. Service Switching Points and Signaling Links

SSPs are SS7-compatible end office or tandem switches. They communicate with each other and with Service Control Points ("SCPs") through signaling links, which are 56 kbps dedicated circuits connecting SSPs with the mated STP pair serving the LATA.

3.1.2.7. Service Control Points

SCPs are databases residing in an SS7 network that contain various types of information, such as IXC identification or routing instructions for 800 numbers in regional 800 databases, or customer line information in Line Information Databases ("LIDB").

4. HM 5.0a Model Organization, Structure and Logic

4.1. Overview of HM 5.0a Organization

Figure 4 shows the relationships among the various modules contained within HM 5.0a. An overview of each component of the Model follows.

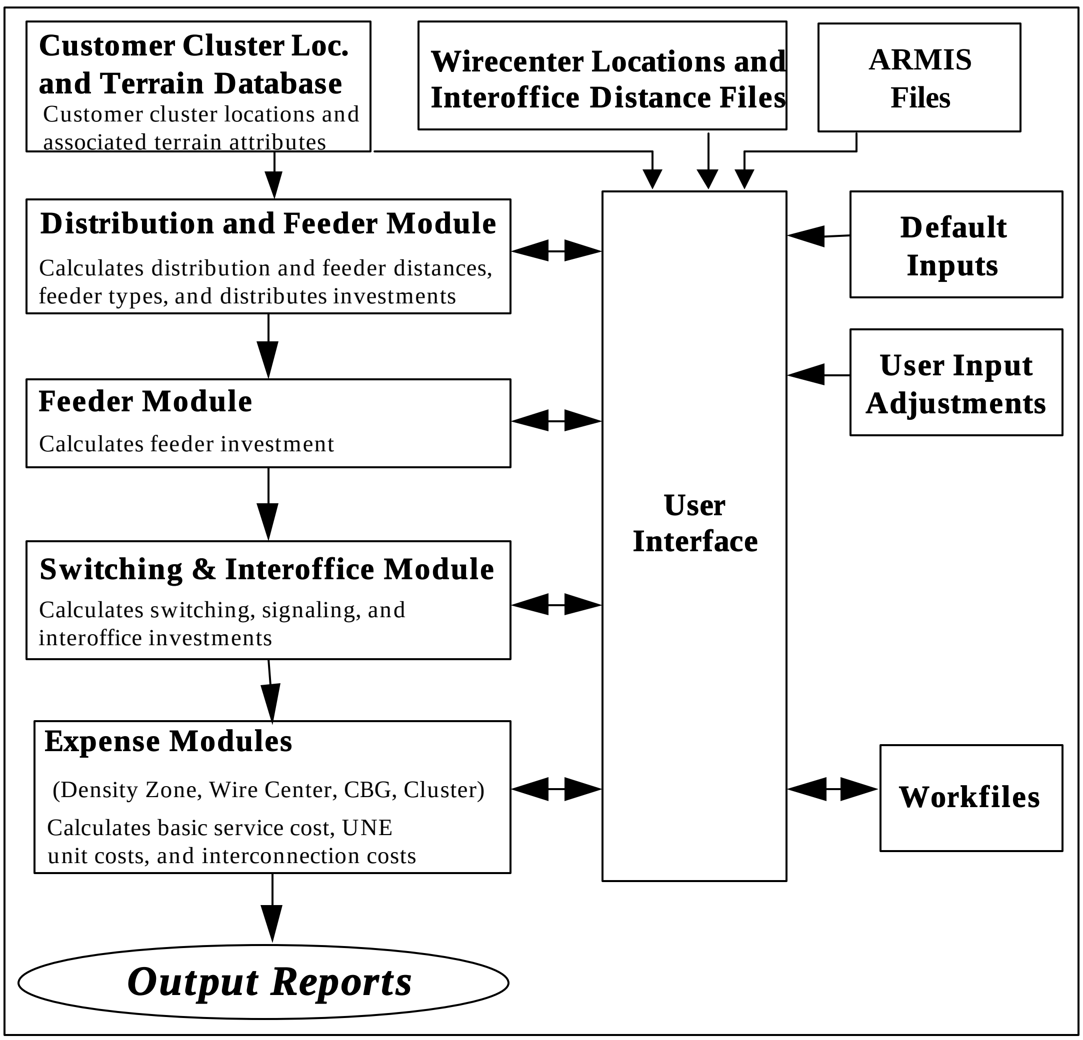


Figure 4 HM 5.0a Organization Flow Chart

4.2. Input Data

Inputs to HM 5.0a include detailed data describing the following items.

- Demographic, geographic and geological characteristics of the areas served by each telephone company. These data records are specific to individual "clusters" of customer locations (i.e., "main" clusters and their subtending "outlier" clusters). They include information on the number of customer locations and lines receiving telephone service in a cluster, the geometric configuration of the cluster's boundaries, the wire center that serves the cluster and the cluster's location relative to this wire center and to other nearby clusters, and the type of terrain that characterizes the cluster. The character and development of these data are described in greater detail in Section 5.

- Wire center locations, and interoffice distances between end offices, tandems, and STPs used to determine the route miles required for interoffice transmission and signaling facilities. These data are largely developed from Bellcore's LERG and NECA Tariff 4.

- 1996 ARMIS data reported by the Tier 1 LECs. These data provide information about current demand levels that the LEC must serve, and relationships between the LEC's embedded expenses and investments.

- Numerous user-adjustable inputs that allow users to set carrier- or locale-specific parameters, and perform sensitivity analyses. These inputs have preset default values based on the engineering experience and judgment of HAI personnel, as well as the judgements of independent subject matter expert consultants to HAI.

4.3. Workfiles

A run "workfile" is created from the input data files when a particular state/company (i.e., study area) combination is run for the first time. As a complete run of the HM 5.0a progresses, intermediate outputs from the HM 5.0a's constituent modules are stored in the run's workfile. Once the run is complete, its workfile may be examined. A great deal of information above and beyond that presented in the Expense Module spreadsheets (that contain the principal final results of the model's analysis) may be obtained from the run's workfile. One example is average loop length, by cluster and by wire center. Additionally, the user may perform separate analyses on the LEC study area by directing the model to create a new workfile for a subsequent run.

4.4. User Interface

The HAI Model includes a user interface program that facilitates model operation, including extraction of data from the input files, providing dialog boxes for users to manipulate model inputs, executing the Excel workbooks that constitute the model, saving intermediate results, and managing the flow of intermediate results between different modules.

The user interface program also performs certain simple aggregation and summarization calculations in Visual Basic for Applications ("VBA"). This shortens greatly execution times and allows users examining the model's Excel workbooks to focus on the model's fundamental engineering logic.[16]

4.5. Distribution Module

The Distribution Module addresses the portion of the network extending from SAIs to the customers' premises. The module determines the lengths and sizes of distribution cable, the associated structures (poles, trenching, and conduit), the number of terminals, splices, drops, and NIDs required to provide service to the specified numbers and types of customers, and the number and type of SAIs and DLC terminals required. The module also calculates certain distances required by the Feeder Module, and, according to those calculations, determines whether to serve a given distribution area using feeder transmission facilities consisting of copper wire pairs, or using DLC running over optical fiber cable. The model selects fiber feeder if any of following five criteria are met:

a) the feeder distance exceeds a user-adjustable crossover distance (set to a default value of 9,000 feet) that limits maximum distance of any copper feeder run;

b) the total copper loop length, including feeder and distribution cable, for customer locations within a main cluster, exceeds a user-adjustable maximum analog copper distance whose default value is 18,000 feet;[17]

c) the main cluster has at least one outlier cluster subtending it;

d) an analysis of the life-cycle costs of fiber vs. copper feeder shows that fiber feeder is the more economical choice, or

e) the "wireless" investment cap is invoked.

These criteria are described in greater detail in Section 6.3.5. If, based on these criteria, copper feeder is chosen, it extends out to an SAI located at the centroid of the main cluster. Copper distribution cable then extends from the SAI to all customer premises in the cluster. If fiber feeder is chosen, it extends from the wire center out to the centroid of the main cluster. From this point, one of two configurations is used to serve the customer locations within the main cluster. If the distance to the farthest customer location in the

[16] Model versions prior to HM 3.0 used Microsoft Excel's Pivot Table feature to summarize various results at the wire center and density zone levels. Although this feature was quite flexible, applying pivot tables to the very large arrays of data required by the model led to very slow execution times.

[17] The analog copper distance refers to the distance over which signals are transmitted in analog voiceband form on copper cable.

main cluster is less than the user-adjustable maximum analog copper distance, a single DLC RT is located at the cluster centroid, and copper distribution cable extends from this DLC RT to all customer premises in the main cluster. If the distance to the farthest location in the main cluster exceeds the maximum analog copper distance, then fiber connecting cable extends vertically and/or horizontally from the centroid to two or more DLC RTs, each of which serves a portion of the main cluster and is located to ensure the longest remaining distance is less than the maximum analog copper distance. From these multiple DLC RTs, copper distribution cables extend to the customer premises in the portion of the main cluster they are responsible for serving.[18]

The HM 5.0a Distribution Module serves outlier clusters that subtend main clusters with analog copper cable if their distance from the DLC RT in the main cluster does not exceed the user-adjustable maximum analog copper distance parameter, and if this outlier cluster has no other outlier clusters either subtending it, or lying between it and the main cluster.[19] If the distance to the farthest subscriber within an outlier cluster would exceed this threshold, the Distribution Module serves the outlier cluster with digital loop carrier equipment using copper-based T1 digital transmission.[20] Once the outlier cluster has been reached, analog copper distribution cables are used to serve the customers located in the outlier cluster.

After the module has determined the quantities of all distribution elements, it calculates the investment associated with these elements, including distribution and drop cable, structures, NIDs, terminals and splices, SAIs, and DLC terminals, using as inputs the user-adjustable unit prices of each element. The numbers and types of elements engineered can be examined in the intermediate outputs of the Distribution Module as recorded in the workfile.

4.6. Feeder Module

The Feeder Module configures the portion of the network that extends from the wire center to the SAIs. Based on information it receives from the Distribution Module, it determines the size and type of cables required to reach the SAIs located in each serving area, along with supporting structures (poles, trenching, conduit, manholes, and fiber optics pullboxes). The Feeder Module then calculates the investment associated with these elements, using as inputs the unit prices of each such element. It passes these investments to the Expense Modules. The numbers and types of network elements required can be examined in the intermediate outputs of the Feeder Module as recorded in the workfile.

[18] If, however, the model invokes a wireless local distribution system, fiber feeder extends to the radio base station located in main cluster, and final distribution is made to customers in outlier clusters over-the-air.

[19] Such an outlier cluster is termed a “first order” outlier.

[20] This technology does not require the use of loading coils or coarse-gauge cable, and it also permits basic rate ISDN and other advanced narrowband services to be provided to all subscriber locations in the model.

4.7. Switching and Interoffice Module

The Switching and Interoffice Module computes investments for end office switching, tandem switching, signaling, and interoffice transmission facilities. In HM 5.0a the user can designate specific wire center locations that house host, remote, and stand-alone switches, respectively, as well as specify inputs for the per-line investments associated with each type of switch. HM 5.0a will then calculate switching investments taking into account the switch arrangements that the user designates.

The switching module determines the required line, traffic, and call processing capacity of switches based on line totals by customer type across all serving areas belonging to the wire center, and based on ARMIS-derived traffic and calling volume inputs. It also determines the required capacity and distances of interoffice transmission facilities, using the traffic data and the interoffice distances that are input to the Module. In doing so, it uses wire center locations and interoffice distances to determine an efficient mix of interoffice SONET fiber rings and redundant point-to-point fiber links. Rings are separately provided for linking host switches to their subtending remotes, and for linking host switches to each other, to stand-alone switches and to the tandem switches on which they home.[21] The numbers and types of elements involved can be examined in the intermediate outputs of the Switching and Interoffice Module as recorded in the workfile.

4.8. Expense Modules

There are four different versions of the HM 5.0a's Expense Module – one for each of the four levels of granularity at which the user can elect to have cost results displayed: by line density range (which also displays total study area costs), by wire center, by CBG, or by customer cluster.[22] Each version calculates the monthly costs for unbundled network elements, universal service, and carrier access and network interconnection. These costs include both the capital carrying costs associated with the investments, and the costs of operating the network. Capital carrying costs include depreciation, return on the debt and equity investment required to build the network, and income taxes on equity return. Network-related expenses include maintenance and network operations. Non-network related expenses include customer operations expenses, general support expenses, other taxes and variable overhead expenses.

Several sources provide information to the Expense Modules. The Distribution, Feeder, and Switching and Interoffice Modules provide network investments by specific plant

[21] At the user's option, small standalone wire centers serving fewer lines than a user-adjustable threshold (default value: one line) may be excluded from being placed on rings, and instead linked directly to its serving tandem using point-to-point links. In this case, the model attempts to physically route these point-to-point circuits through a nearby large wire center, and then over the fiber rings it has otherwise engineered for interconnecting larger offices and tandems.

[22] Although the HM 5.0a engineers no plant based on CBG granularity, the results of its engineering to individual clusters may be rolled up to display cost results at the CBG level. The association between clusters and CBGs is made based on the relative number of lines each cluster contributes to a CBG's total.

category. ARMIS and other sources are used to derive information on network operating and maintenance expense relationships.

The Expense Modules produce reports (either by density zone, wire center, CBG, or cluster) showing the key outputs of the model, including the costs of providing universal service, unbundled network elements, interconnection and IXC access. Further detail about network investments and costs is available from the workfile associated with a model run.

5. Input Data

To accommodate HM 5.0a's evolution to modeling local telephone networks based on actual clusters of customer locations, the input data used in HM 5.0a are much more granular than the CBG input data used in HM 4.0 and earlier. Flowcharts describing the development processes used to prepare these input data for HM 5.0a are attached as Appendix C to this document.

5.1. Line Type Counts by Study Area

Counts of access lines by type (i.e., residence, single line business, multiline business, public telephone and special access lines) for each distinct NECA Study Area for calendar year 1996 are developed from several data sources. These include:

ARMIS 43-08: 1996 data, released 10/01/97;
ARMIS 43-01: 1996 data, released 10/01/97;
NECA USF Loops filing: 1996 data;
USTA report: 1995 data;
RUS report: 1995 data;
USF Data Request: 1993 data;
ARMIS-based line factors.

The rules by which the best of these data are selected are as follows.

a) When NECA Study Area name matches exactly ARMIS Company name, populate line types directly from ARMIS data for business lines (43-08), single line business lines (43-01), residence lines (43-08), special access lines (43-08), and public lines (43-08) data.

b) For remaining ARMIS Companies, determine counts of line types for NECA Study Area name by applying ARMIS line type distributions to total reported NECA USF Loops.

c) For non-ARMIS Companies, match NECA Study Area name to best available data source (i.e., USTA, RUS or USF Data Request) for residence and business line splits.

d) When no company-specific line type data exist, apply average ARMIS line type distributions to reported NECA USF Loops for NECA Study Area name.

5.2. Wire Center List

The source of the wire center information used in PNR's National Access Line Model is Bellcore's LERG database, dated August 1, 1997.[23] The portions of these LERG data that are used in the HAI model are an extract of key data from the LERG called the Special LERG Extract Data ("SLED") – which has been licensed from Bellcore by the HAI model developers.

Certain switching entities (wire centers) in the SLED with Common Language Location Identifier ("CLLI™") codes not marked as end offices, hosts or remotes are then removed from this wire center database. In addition, switching entities that are inactive, or owned by wireless, long distance or competitive access providers are removed as well.

In a few instances, the SLED assigns wire centers to multiple local carriers. This may result from switch collocation. Because the HAI Model requires wire center entries to be unique, such wire centers are assigned to the local carrier having the greatest number of active NPA-NXX codes. If active NPA-NXX codes are equal among companies, assignment is to the carrier having the greatest number of residential lines.

Multiple occurrences of 8-character CLLIs may also occur in the SLED due to placements of several switches at a single wire center location. Because the HAI Model itself engineers multiple switches in a wire center if demand requires it, duplicate occurrences of 8-character CLLIs are removed from the model's wire center list.

5.3. Customer Counts by Census Block and Wire Center

Customer locations must be associated both with CBs, as well as their serving wire center ("WC"). The PNR National Access Line Model, Version 2.0 ("NALM") performs both of these tasks. The PNR NALM uses PNR survey information, Bellcore's LERG, BLR wire center boundaries, Dun & Bradstreet's ("D&B") business database, Metromail's household database, Claritas' 1996 demographic database, and U.S. Census estimates to calculate both the number of residential and business locations and access lines in each CB, and in each wire center in the United States. This summary describes the methodology, data and assumptions used in developing these location and line estimates in the NALM.

5.3.1. Residence Counts

Residential customer location counts are developed by applying the following process.

a) The Metromail household database (described in section 5.4.1, below) is geocoded to the "point" level.[24] In addition to recording the precise six-decimal place latitude and longitude of this household, the CB associated with its location

[23] These LERG data are augmented by data from NECA Tariff 4.

[24] As described in more detail in Section 5.4.3, below, geocoding to the "point" level means that the geocoding software has both found the housing unit's address in its location files and determined a latitude and longitude for the location down to six decimal places of a degree.

is recorded as well. Duplicate household information is identified and eliminated. If two records appear with an identical latitude, longitude and phone number, one of the two records is eliminated.

b) Implied residential household counts are evaluated by comparing Metromail counts to Claritas' 1996 CBG-level projections of households with telephones. When Metromail households exceed Claritas households, Metromail households are used. When Claritas households exceed Metromail households, Claritas households are used, and the total differences are distributed to the constituent CBs in proportion to 1990 U.S. Census household distributions.

c) Access line counts are determined from household counts using probabilities, that is, how likely is it that a household will have a first or second telephone line installed? First line probabilities are provided by Claritas based on demographic age and income profiles by CBG. Second line probabilities are based on a logistic regression using similar demographic information and developed by PNR using its ReQuest™ III residential survey. Multiplicative probability factors are applied to the household counts defined above to derive residential line counts.

d) The above derived residential line counts by CB are then normalized to sum to Study Area wide data on total residential line counts developed in Section 5.1, above.[25]

e) This lines normalization factor is applied to the residential customer location counts in each CB, as well.

The implications of the forgoing process are as follows. Because the primary source of residential location counts is Metromail – which includes all residences that receive direct mail regardless of whether they have telephones or not – the universe of "populated" CBs that the data process captures may include CBs where telephone service is not currently offered or accepted. Thus, the "breadth" of the telephone network that these data will instruct the HM 5.0a to construct is likely greater than the embedded networks of the ILECs. However, because the counts of lines and locations in each CB are normalized to sum to given Study Area wide totals, the "depth" of the constructed network will be consistent with current levels of actual telephone demand.[26]

5.3.2. Business Counts

[25] If comprehensive LEC data on residential line counts by individual wire center are available, normalization can be done at the individual wire center level.

[26] In addition, note that these primary source residential location counts derive from precisely geocoded 1997 Metromail data. Thus, these data provide 1997 information on location counts at the CB level. As a result, the model's reliance on noncurrent or nonCB-specific location data (e.g., Claritas 1996 CBG-level projections, 1990 U.S. Census CB counts, or 1995 U.S. Census Update county-level projections) is limited to those locations that show up in such counts that are in excess of the Metromail counts.

Business location counts are developed by applying the following process.

a) The D&B national business database (described in Section 5.4.2, below) is geocoded to the “point” level. In addition to recording the precise six-decimal place latitude and longitude of this business, the CB associated with its location is recorded as well.

b) From the D&B national database, the total number of business lines, as well the probabilities of these lines being single line business lines and multiline business lines such as Centrex and PBX lines are developed. This model is based on an 800,000 firm sample.

c) Because the D&B national business database contains records for only about 11 million out an estimated total of 12 million U.S. businesses, and because the businesses that it misses are almost certainly small businesses, an additional 1 million nonD&B business locations are added to CB counts in proportion to D&B businesses located in the CB. The lines associated with these added business locations are projected by PNR based on an assumption that they employ, on average, between 1 and 4 employees, each.[27]

d) The above derived business line counts by CB are then normalized to sum to Study Area wide data on total business line counts developed in section 2.1, above.[28]

5.3.3. Location and Line Counts by Wire Center

HM 5.0a uses WC boundaries provided by BLR as its primary source to define wire center service areas. These boundaries conform to CB boundaries, and customer locations contained within all of the CBs associated with a WC are then assumed to be served by that WC. Telephone number information (NPA-NXX) continues to be used for backup and data scrubbing purposes when anomalies arise in the BLR geographical assignment process – as can occur if one wire center’s boundaries fall completely within another wire center’s boundaries.

5.4. Customer Location

The customer location approach used in HM 5.0a is fundamentally different from that of HM 4.0 – or any other approach that uses arbitrary geographic delineators such as CBs, CBGs or latitude and longitude grid cells. Because HM 5.0a’s approach identifies the actual locations (accurate to within 50 feet) of most telephone customers, it produces the

[27] To the extent that the D&B database contains firms that are not locatable to the CB-level, these firms are assumed to be distributed across CBs in proportion to located firms within D&B. Their line counts are calculated based on the company characteristics (e.g., employees, SIC) that they report to D&B.

[28] Again, if comprehensive LEC data on business line counts by individual wire center are available, normalization can be done at the individual wire center level.

most sophisticated demographic data set of its type. The process first develops a database of about 109 million customer address records. These addresses are then geocoded (assigned latitude and longitude coordinates). These locations are then divided among wire center serving areas based on geocoded customer location and the BLR wire center boundaries.

5.4.1. Residence Location Data

Data for residence locations are provided by Metromail, Inc. The Metromail National Consumer Database© ("NCDB") is a large, nationally compiled file of U.S. household-level consumer information that includes both deliverable postal addresses (and telephone numbers, when available). The file consists of close to 100 million records – which constitute over 90% of all residential housing locations that the U.S. Bureau of the Census reported for 1995.[29]

To ensure that the data captured are the most current available, this file is updated 65 times per year, and undergoes numerous "hygiene" measures to ensure its continued high quality for direct marketing purposes. Such purposes require the data to reflect postal address standardization practices, incorporate National Change of Address ("NCOA") processing, and permit postal geocoding to street address, ZIP+4 or Carrier Route levels.

The file is compiled primarily from telephone white pages directory data, but also utilizes many other primary sources of information, such as household mover records, voter registration data, motor vehicle registration information, mail-order respondent records, realty data, and home sales and mortgage transaction information, to build a large repository of verified household-level data.

5.4.2. Business Location Data

Dun & Bradstreet collects information on more than 11 million business establishments nationwide. Information is gathered from numerous sources such as business principals, public records, industry trade tapes, associations, directories, government records, news sources, trade organizations, and financial institutions. This information is validated each night. Additionally, D&B conducts millions of annual management interviews to help improve the timeliness and accuracy of its information.

The information is organized by D-U-N-S number, a nine digit identification sequence which allows for the placement of companies within larger business entities according to corporate structures and financial relationships. A D&B family tree may be used to relate separate operating companies to each other, and to their ultimate parent company. D&B also provides "demographic" information on each of the firms in its database. Such information includes counts of employees and the SIC code of the establishment.

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[29] This number is also very close to the 101 million households that the FCC finds in 1996, and exceeds the 95 million households that the FCC reports had telephones in that year. See, *Trends in Telephone Service*, FCC Common Carrier Bureau, Industry Analysis Division, March 1997, Table 1.

5.4.3. Geocoding

Geocoding is used in order to most accurately assign known customer locations to actual, physical locations. Geocoding is also known as location coding. It involves the assignment of latitude and longitude coordinates to actual street addresses. Geocoding software is sophisticated enough to provide information regarding the source and precision of the lat/long coordinates selected. This precision indicator allows PNR to select only those addresses that have been geocoded to a highly precise point location. Geocoding also allows customer location points to be assigned less granularly to the CBG level, or higher. Almost uniformly, geographical address locations are derived from enhanced versions of the USGS' TIGER database.

To perform its geocoding, PNR uses a program by Qualitative Marketing Software called Centrus™ Desktop. The enhanced data behind Centrus is provided by GDT. Premium GDT data are updated bi-monthly to ensure accuracy. These data integrate new information from US Postal Service ("USPS") databases and private sources so that new streets and additions and changes to ZIP codes, street names, and address ranges are included as soon as possible.

Centrus™ Desktop allows geocoding on two levels. The first is a match to the actual address -- which is the only type of geocoding used in HM 5.0a customer location. The second is a match to a ZIP code (ZIP, ZIP+4, ZIP+2) level. Because of the lesser accuracy in the second method, these geocodes are not used in PNR's process of assigning customer locations.

Within the geocode process, there are a number of options available to the user. Each of these options determine the quality of the matches allowed in the end-use geocode. For purposes of customer location, addresses are always matched to the "Close" setting. "Close" allows for minor misspellings in addition to incorrect or missing directionals (North, East, etc.) or street types (street, road, etc.). Although ZIP-based geocodes are generally accurate enough for most applications, they are not considered good enough for actual customer locations and are not used to develop and locate customer clusters in HM 5.0a.

Data hierarchy in address geocoding starts with the State. The hierarchy continues with City, Street Name, Street Block, and finally, House Range. Typically, a Street Block is the same as an actual physical block but it can also represent a partial block as well. The House Range displays address information from the USPS. Additionally, where there are gaps in the actual address range, the House range will account for these gaps.

Initially, the address coding module in Centrus™ Desktop compares the street addresses from the input file to the records contained in the USPS ZIP+4 directory and the enhanced street network files. If the address is located in the USPS files, the address is standardized and a ZIP+4 is also returned. If this address is also found in the street network files, Centrus™ Desktop determines a latitude and longitude for the location.

Optionally, if the address is not found in the street network files, location information may be applied from the ZIP level.[30]

Location codes generated by Centrus™ Desktop indicate the accuracy of the geocode. For purposes of customer location clustering in the HM 5.0a only those geocodes assigned at the 6-decimal place point location made directly to the street segment are used.[31]

While the software and data used allow for a much more comprehensive output of data elements, for use in HM 5.0a customer location, the following addressing elements are extracted:

Address
City
State
ZIP
ZIP+4
Latitude
Longitude
Census Block
Match Code
Location Code

5.4.4. Gross-up

The above-derived precisely geocoded locations are then counted by CB. These geocoded location counts by CB are then compared to target total line counts for that CB derived by the PNR NALM (as described in section 2.3, above). If the geocoded location counts are less than the target count, the residual number of customer location points is then computed, and geographical locations for these points are generated. This process is performed by PNR using TIGER file CB boundaries. Each of the additional number of customer location points that a CB requires to total to its target count is generated and assigned a geocode so as to place these "surrogate" points uniformly along the CB's boundary. While these boundary-assumed locations for the gross-up or surrogate points are plausible – because most CBs are bounded by roads – this is also a conservative placement of the gross-up points because it assumes they are maximally separated from one another.

[30] Note that ZIP+4 codes may be very precise. In general, they are specific to the face of single city block. While it may turn out that accuracy to the street block face is quite sufficient for accurate cost modeling of local telephone networks, in the interest of conservatism, these type of geocodes are not presently used in HM 5.0a data.

[31] Furthermore, placement of the address along the street segment is quite precise. The Centrus geocoding software and reference data also make use of USPS determinations of whether the segment contains a continuous or discontinuous range of address numbers. Thus, if the addresses on a block face run from 200 to 250 and 274 to 298 (with the range between 252 and 272 missing), an address of 250 will be geocoded, it will not simple be geocoded as at midblock.

As a result of this gross up process, the customer location file now contains records for each of the U.S.'s more than 100 million customer locations with a geocode (either calculated precisely or through the gross up process) associated with it.

5.5. Customer Location Clustering

5.5.1. General Criteria

The input development process next identifies all customer locations within a wire center's boundaries that are close enough together to be efficiently engineered as a single telephone plant serving area. This process is called clustering. While there are many available off-the-shelf clustering algorithms, efficient determination clusters of customer locations that are consistent with telephone engineering practices requires that certain engineering restrictions be imposed during the clustering process, and not afterward. Customer locations must meet the following criteria to be considered members of a particular cluster.

- No point in a cluster may be more than 18,000 feet distant (based on right angle routing) from the cluster's centroid.
- No cluster of nondegenerate area may exceed 1800 lines in size.[32]
- No point in a cluster may be farther than two miles from its nearest neighbor in the cluster.

Note that other than for the wire center boundary restriction, these criteria do not include any arbitrary geographic restrictions, such as clusters being restricted to lie within a single CBG, CB, or latitude/longitude grid cell. Thus, clusters developed pursuant to this process are likely to be the most closely representative of actual telephone distribution areas as determined by outside plant engineers. Note, however, that the last of these restrictions – no point in a cluster may be farther than 2 miles from its nearest neighbor – is not an absolute engineering limitation. It is used to ensure that customer locations that are separated by the given distance are not required to be clustered together. It is possible that efficient engineering of telephone distribution plant would suggest that a different, possibly larger value be chosen.[33]

[32] This restriction is based on the maximum unconcentrated lines capacity of an OC-3 fiber optic transmission system used to feed a DLC remote terminal (adjusted for a 90% rate of fill). This is consistent with current HM 5.0a practice that provides a separate channel for each line served by a DLC system. Because it is reasonable engineering practice to concentrate traffic on these large fiber optic DLC systems, future versions of the model may assume that traffic is concentrated on the fiber optic systems feeding DLC remote terminals. When such revisions to the HM become available, the customer location data will be reclustered with the appropriately enlarged maximum limit on cluster size. In all events, if single customer locations, such as a large office or apartment building, by themselves exceed 1800 lines, such clusters are not split. Rather, multiple DLC RTs/SAIs will be placed to serve such "oversized" clusters.

[33] Testing of different parameterizations for the maximum distance to a cluster point's nearest neighbor suggests that 2 miles is a reasonable national value.

5.5.2. Clustering Algorithm

The process used by the PNR clustering algorithm is as follows.

a) First, to provide a uniform geographic unit for clustering operations, all customer location geocodes associated with a particular wire center are "rasterized" into 150 foot cells that overlay the geographic rectangle covering the wire center's service area.[34]

b) The algorithm then inspects all neighboring cells (e.g., all cells that have their center within a 150 foot radius of the center of the initial cell) to see if any are populated with customer locations. If one of these neighboring raster cells is populated, the algorithm first checks to see whether clustering that cell (and its immediately surrounding neighbors) with the initial cell would violate any of the clustering restrictions (i.e., create a cluster that has points more than 18,000 feet from the cluster centroid, create a cluster of more than 1800 lines, or include a point more than 2 miles from its nearest neighbor).[35] If none of these conditions would be violated, the adjoining cell plus its immediate neighbors will be added to the initial cell's cluster

c) This process continues on to the next unclustered populated cell and performs the analysis described in step (b), above. This repeats until no more unclustered cells exist.

d) The process then restarts at step (b), but uses a 300 foot search for populated neighboring cells.

e) This continual enlargement of the search for neighboring populated cells continues on until no more cells can be added to the cluster without violating one or more of the engineering requirements. At this point, the algorithm is complete.

Clusters that contain five or more customer locations are classified as "main" clusters. Clusters that contain from one to four customer locations are called "outlier" clusters. Outlier clusters may be linked to their "home" main cluster via "chains" that string together other outlier clusters that home on the same main cluster. The process of determining the routing of the chain is as follows.

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[34] Rasterization at this level is a process whereby all customer locations that are within the 150 foot square cell are counted as being placed at the center of the cell. Rasterization to 150 foot square cells ensures that the mathematical clustering process can proceed efficiently, and that nonmeaningful distinctions in customer location are ignored. Increasing the raster to 300 or 500 feet would speed up the clustering process dramatically, and still provide a very acceptable level of precision in cluster formation. Note, too, that the PNR calculation of 150 foot raster cells is precise – based on the local latitude of the cell. Thus, raster cells do not enlarge as one moves south toward the equator.

[35] Because the rasterization into 150 foot square cells may cause customer locations that actually are in the farthest corner of a cell to be considered at the cell's center, the clustering algorithm will actually check to ensure that no cells added to a cluster exceed 17,700 (= 18,000 - 2∗150) feet from the cluster's centroid.

a) The clustering algorithm first calculates the distance between each cluster and every other cluster in the wire center service area.

b) The algorithm then determines the shortest distance between any two clusters, and associates these two clusters together.

c) Next, the algorithm determines the next shortest distance between any two clusters or cluster chains, and associates these together.

d) This process continues until all outliers are chained to a main cluster.

In addition to creating chains to associate outlier clusters to a main cluster; the clustering algorithm calculates the centroid location, "aspect ratio" and area of the rectangle that overlays the convex hull of each cluster; and that has the same centroid location, aspect ratio and area as this convex hull.[36]

When this process is completed, the main cluster and its subtending outliers are considered to constitute one serving area.

The description the HM 5.0a Distribution Module in Section 6.3 provides greater detail on the model's engineering of outside plant to serve main and outlier clusters.

5.6. PointCode Translation Processes

PointCode is a Microsoft Access '97 database process that translates between coordinate systems, computes distances and assigns additional characteristics to cluster records. Among the activities executed by PointCode are the following.

Convert the latitude and longitude coordinates provided by PNR for cluster centroids to V&H coordinates. Ensure that modeled distribution rectangles have an aspect ratio and area that reflects a minimum dimension equal to twice the default drop length for that lines density range. Calculate radial distances between main clusters and their serving wire center. Calculate radial distances between outlier clusters and main clusters.

Compute omega angles between main feeders and the clusters they serve and compute alpha angles between clusters and their subfeeders. Calculate rectilinear (right angle) distances between main clusters and their serving wire center, and between outlier clusters and main clusters.

On the basis of the characteristics of the covering CBG, assign terrain and lines density zone characteristics to the cluster.

[36] The convex hull of the cluster is the convex polygon that has as its boundary the outermost points of the cluster – as such, it covers all of the points in the cluster. The aspect ratio is the ratio of the North-South length to the East-West length of the convex hull of the cluster.

6. Module Descriptions

6.1. Input Data Files

6.1.1. Demographic and Geological Parameters

Demographic and geological parameters are obtained from a database developed by PNR and Associates of Jenkintown, PA. Section 5, above, explains in detail how these data are developed. The data file resulting from these processes is organized by state and telephone company (study area). Each customer location cluster (both main and outlier) identified in the wire center service areas of the LEC modeled appears as a separate record in this Microsoft Access 97 database. Each of these cluster records contains the following information:

- Identity of the LEC and wire center serving the cluster;
- Locational information about the cluster relative to its wire center, the predominant CBG in which it falls, its nearest neighboring cluster and associated distances;
- Area and dimensional measurements of the cluster and its lines density;
- Terrain and geological parameters;
- Number of telephone lines by type;
- Number of households and number and type of housing units;
- Number of business firms and employees;
- Information about the fraction of a wire center’s total lines are represented by this cluster, the average loop distribution distance of its subtending outlier clusters and total number of outlier lines.

The complete list of data fields in the Cluster Input data table is as follows:

Cluster Input Data Table		
State	Total Area	1-HU detach
CLLI	Aspect Ratio	1-HU attach
Company	Company State	HU-2
Neca_ID	Density Lines/SQ Mile	HU-4
Group	Rock Depth	HU-5-9
CBG	Rock Hard	HU-10-19
Cluster Group	Surf Text	HU-20-49
Overall Quad	Water Depth	HU-50+
Overall Omega	Total Lines	Mobile
Overall Alpha	Total Bus Lines	Other
Radial Dist Feet	Total Res Lines	Firms
Cluster or Outlier Check	Special Lines	Employees
Outlier Quad	Public Lines	FracWCLine
Outlier Omega	Single Line Business	AvgLoopDist
Outlier Alpha	Households	TotOutLine
Outlier Radial Distance		

6.1.2. Wire Center Locations and Interoffice Distances

Calculations to determine total route-miles of interoffice facilities require as inputs several distance measures. These include the distances between each LEC EO and the tandem switch that is assumed to serve it, the distance between the EO and the STP pair that serves it, distances between STPs, distances between tandem offices, and the V&H (vertical and horizontal) coordinates of each switching entity. These data are calculated from a database licensed from Bellcore, referred to as the Special LERG Extract Data ("SLED") file which contains information from the Local Exchange Routing Guide ("LERG"). The SLED includes the V&H coordinates of each switching entity, and the nature of the entity, e.g., end office, tandem, STP, multiple use, etc. Appendix D provides an outline of the process used to develop these distance measures.

6.1.3. ARMIS Data

These data are obtained from the 1996 ARMIS 43-08 Operating Data Reports. ARMIS data are submitted to the FCC annually by all Tier 1 LECs.[37] The following elements of these data are extracted.

[37] See, Reporting Requirements for Certain Class A and Tier 1 Telephone Companies (Parts 31, 43, 67 and 69 of the FCC's Rules), CC Docket No. 86-182, 2 FCC Rcd 5770 (1987) (ARMIS Order), modified on recon., 3 FCC Rcd, 6375 (1988). Tier 1 LECs are those with more than $100 million in annual revenues from regulated services. This includes over 50 carriers.

- The number of residential access lines, including all residential switched access lines, including those with flat rate (1FR) and measured rate (1MR) service.

- The number of business access lines, including analog single business lines, analog multi-line business lines and digital business lines; these totals include flat rate business (1FB) and measured rate business (1MB) single lines, PBX trunks, Centrex lines, hotel/motel, long distance trunks and multi-line semi-public lines.[38]

- Analog and digital special access lines, including dedicated lines connecting end users' premises to an IXC POP, but do not include intraLATA private lines.

- Public access lines, which include lines associated with coin (public and semi-public) phones, but exclude customer owned pay telephone lines.[39]

For companies that do not report ARMIS, HM 5.0a makes use of data reported in various sources listed earlier in Section 5.1.

6.1.4. User Inputs

This category comprises over 1400 user-definable values. These range from the price of network components, to the percentage of joint-use end offices and tandem offices to capital structure. HAI has supplied default values for each of these variables based on its collective judgment, as augmented by subject matter experts in various areas of network technology, operations and economics. Users can vary these default parameters to reflect unusual local conditions. Appendix B contains a complete description of these variables, along with the default values that have been assigned to them.

6.2. Outside Plant Engineering

The Distribution and Feeder Modules are the main modules controlling the engineering of outside plant. While Sections 6.3 and 6.4 below discuss the unique aspects of each of these modules, this section describes several features and assumptions common to both modules.

Figure 5 shows the basic outside plant serving configuration used by HM 5.0a.

[38] *Id*. at 1-2.

[39] *Id*. at 2.

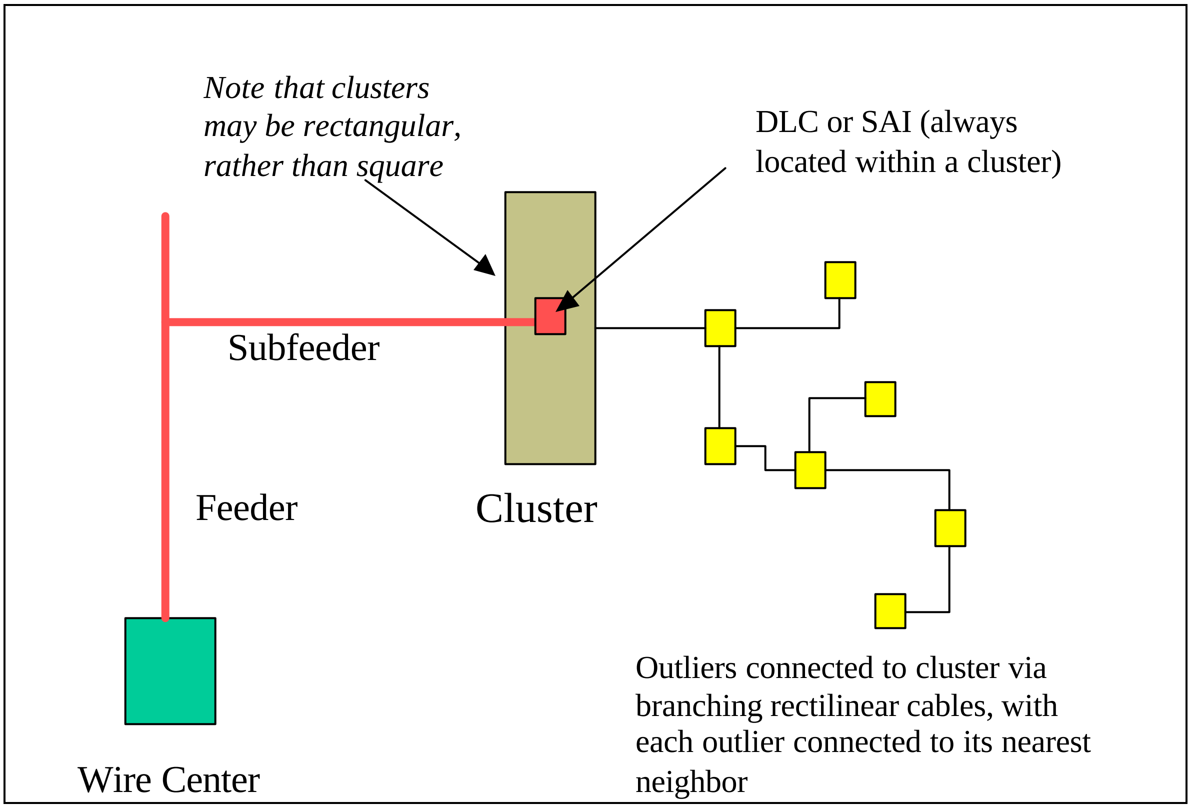

Figure 5 Loop Outside Plant Configuration

The Model assumes a main cluster and its subtending outlier clusters constitute a serving area. Main feeder cable (that may be shared with other main clusters) and subfeeder cable extend from the wire center to the centroid of the main cluster. If the main and subfeeder cable are copper, the subfeeder cable terminates in an SAI. If the feeder and subfeeder are fiber, the subfeeder either terminates at a single DLC RT and adjacent SAI located at the centroid of the main cluster, or extends via fiber "connecting cables" from the centroid to two or more DLC RTs and adjacent SAIs located within the cluster so as to ensure no copper distribution cable length exceeds the user-adjustable maximum analog copper distance. The choice between copper and fiber main feeder and subfeeder is made according to the criteria discussed in Section 6.3.5, below. In all cases, analog copper distribution cables extend from the SAI(s) to their subtending customer locations within the main cluster in a backbone and branch fashion. The data process used to locate customers and identify population clusters also determines the "aspect ratio" of the overlying rectangle that defines the boundary of a main cluster, and is used in determining the location of the fiber DLC RTs and layout of the backbone and branch distribution arrangement.

From the centroid of a main cluster, copper cables extend to each outlier cluster that is served from that main cluster, with each outlier cluster connected to its nearest neighbor (either the main cluster or another outlier cluster), via a right-angle route. These copper cables terminate either at an SAI or T1 remote terminal at the centroid of the outlier cluster – depending on whether the distance the signal needs to be carried falls short of, or exceeds, a user-adjustable 18,000 foot threshold. Subscribers in outlier clusters are assumed to be located on routes within the outlier cluster that may be distinct from the route traveled by the cable feeding the outlier's SAI or T1 remote terminal from the main cluster. Because of this, a separate analog copper distribution cable is run from the centroid of the outlier to individual customer locations. The model does, however, assume a moderate amount of structure sharing between these two cables within the outlier cluster because of the partial coincidence of their routes.

6.2.1. Outside Plant Structures

Outside plant structure refers to the set of facilities that support, house, guide, or otherwise protect distribution and feeder cable. There are three types of structure: aerial, buried and underground.

1) *Aerial Structure*

   Aerial structure typically consists of poles.[40] Pole investment is a function of the material and labor costs of placing a pole. A user-adjustable input allows the customization of the labor component of pole investment to local conditions. HM 5.0a computes the total investment in aerial distribution and feeder structure within a CBG by evaluating relevant parameters, including the distance between poles, the investment in the pole itself, the total cable sheath mileage, and the fraction of aerial structure along the route.

   The model assumes forty-foot Class 4 poles. The spacing between poles for aerial cable is fixed within a given density range but may vary between density ranges. The number of poles on a given route is calculated as:

   $$1 + (\text{route distance/pole spacing}), \text{ rounded up.}$$

2) *Buried Structure*

   Buried structure consists of trenches and related protection against water and other intrusions. The additional cost for protective sheathing and waterproof filling of buried cable is a fixed amount per foot in the case of fiber cable and is a multiplier of cable cost in the case of copper cable.[41] The total investment in buried structure is a function of total route mileage, the fraction of buried structure, investment in protective sheathing and filling, and the density-range-specific cost of trenching.

[40] In the two highest density zones, most aerial structure is assumed to be intrabuilding riser cable and "block cable" attached to buildings.

[41] The default values for sheathing are $0.20 per foot for fiber, and a multiplier of 1.04 for copper. The different treatment reflects the fact that the outside diameter of fiber cable is essentially constant for different strand numbers, while copper cable diameter increases with the number of pairs it contains.

3) Underground Structure

Underground structure consists of conduit and, for feeder plant, manholes and pullboxes. Manholes are used in conjunction with copper cable routes; pullboxes are used on routes that are served exclusively by fiber cable. The total investment in a manhole varies by density zone and includes materials, frame and cover, excavation, backfill, and site delivery. Investment in fiber pullboxes is a function of materials and labor. Underground cables are housed in conduit facilities that extend between manholes or pullboxes. The total investment in underground structure is a function of total route mileage, the fraction of underground structure, investment in conduit manholes, and pullboxes, and the cost of trenching needed to hold the conduit.

In each line density range, there may be a mixture of aerial, buried and underground structure. For example, in downtown urban areas, it is frequently necessary to install cable in underground conduit systems, while rural areas may consist almost exclusively of aerial or direct-buried plant. Suburban areas may have a more balanced mixture of all three structure types. Also, as described more completely in Section 6.2.5, below, the HM 5.0a permits certain amounts of substitution between buried and aerial structure based on abnormal local cost conditions.

Users can adjust the mix of aerial, underground and buried cable assumed within the model. These settings may be specified by density zone for fiber feeder, copper feeder, and copper distribution cables. Appendix B includes detailed lists of the HAI Model structure default values for aerial, buried and underground plant.

6.2.2. Terrain and Its Impact on Placement Costs

HM 5.0a incorporates the effects of geological factors on required structure investment. Terrain factors considered by the model include bedrock depth, rock hardness, surface soil type, and water depth. Each serving area is assumed to have the terrain characteristics of the CBG in which it predominately falls.[42]

If the rock depth in a serving area is less than a user-definable rock depth threshold, a rocky placement multiplier increases structure investment in poles, conduit placement, and trenching, because it is more difficult to bury cable in rock than in soil.[43] If bedrock

[42] Main clusters and their subtending subclusters are not restricted to fall entirely within a single CBG. Such a restriction would impose an artificial limitation on the "natural" serving areas being identified by the Model. As a result, the predominant CBG must be used to determine the terrain characteristics. If appropriately digitally-encoded terrain data become available, a more precise determination of the terrain characteristics of serving areas crossing several CBGs could be made.

[43] The HAI Model default maximum values for geological factors are as follows: rock depth threshold causing increased trenching cost, 24 inches; hard rock placement multiplier, 3.5; and soft rock placement multiplier, 2.0.

does not exist within the placement depth, then the surface soil texture is examined to determine if soil can be plowed, or if more expensive placement techniques must be used. The model causes the rock placement multiplier to vary with rock depth; the entire multiplier applies if the rock depth is zero, and the value tapers linearly to unity at the user-defined placement depth.

Certain kinds of surface textures may increase the cost of structure. When these are encountered, the model extracts a multiplier from a lookup table in the distribution module inputs worksheet, and applies it to the structure investment as determined by the density zone. If both difficult soil conditions and rocky conditions are encountered, the model will multiply the structure investment by the sum of the rock placement and surface texture multipliers minus one.[44]

Water table depth does not have a significant effect on trenching costs, but may affect the cost of placing manholes. The model increases manhole placement costs by a user-adjustable amount (default value of 20%) of the nominal placement cost whenever the water table depth is less than a user-adjustable minimum depth whose default value is five feet.

Labor costs for placement may be adjusted for regional variation by the application of a user-entered labor adjustment factor.

6.2.3. Structure Sharing

Outside plant structures are generally shared by LECs, CATV operators, electric utilities, and others including competitive access providers ("CAPs") and IXCs. To the extent that several utilities may place cables in common trenches, or on common poles, it is appropriate to share the costs of these structure items among these users. Furthermore, manholes may be shared by all low voltage utilities as well. The HAI model assumes sharing of structure costs among the various utilities that occupy the structure. Although assumptions concerning the degree of sharing are user-adjustable; the default values used in the HAI Model reflect best forward-looking, economic practices for the various utilities involved.

6.2.4. Lines Density Considerations

A number of parameters, such as the fill factors for distribution and feeder copper cable and the mixture of underground, buried, and aerial plant, are dependent on line density of the serving area. The line density is defined as the total number of subscriber access lines per square mile. While entire serving areas are associated with a given density zone for purposes of accumulating density zone results, HM 5.0a makes a separate density zone determination for the main cluster and the outlier clusters, based on the CBG to which each belongs, when it is selecting which density-zone-dependent factors to use in a

[44] Section 6.2.5, below, indicates how the Model automatically will adjust the fractions of buried and aerial structure to reflect economic choices based on abnormal local cost conditions for these structure types.

calculation. In HM 5.0a, as in HM 4.0, line density is broken down into nine different density ranges.

Density Ranges (lines/sq. mile)
0 - 5
5 - 100
100 - 200
200 - 650
650 - 850
850 - 2550
2550 - 5000
5000 – 10,000
10,000 +

6.2.5. Economic Adjustment of Structure Fractions

The HM 5.0a Distribution and Feeder modules automatically adjust buried and aerial structure fractions to account for the plant placement costs occasioned by local soil and bedrock conditions. The user specifies nominal buried and aerial fractions, along with an "at risk" portion of the buried cable fraction that unfavorable cost conditions can cause to be shifted to aerial. The model calculates the local relative costs of buried and aerial structure -- including both the additional placement costs arising from local terrain conditions as well as the life-cycle maintenance and capital carrying costs of the different structure types.[45] This local relative life-cycle cost of buried versus aerial structure is then ratioed to the national norm for relative buried to aerial life-cycle cost. The model then adjusts the aerial fraction up or down (and buried fraction in inverse fashion) from its national default value by up to the full amount of "at risk" structure, depending on the degree of difference in local versus national norm life-cycle costs.

A logistic curve is used to specify the sensitivity of structure choice to differences in relative cost. The "s-curve" shape of the logistic function suggests that initial divergences of local relative structure costs from "normal" relative structure costs cause

[45] This calculation of the relative life-cycle costs of plant placed on various different structures is computed as follows. First, per-foot materials' investment costs are calculated, and added to the per-foot investment cost of the particular structure type – adjusted for the assumed amounts of inter-utility structure sharing that apply to the particular structure type. Second, annual charge factors are developed for capital carrying costs and maintenance costs. These factors are developed within the "LCFactors" and "CCCFactor" sheets of the Distribution Module using the same methodologies described in Sections 6.6.2 (for capital carrying costs) and 6.6.3.1 (for network maintenance costs) documenting the HM 5.0 Expense Modules. Finally, the plant net investment cost is multiplied by the sum of the annual capital carrying cost and maintenance cost factors, to yield the relevant annual life-cycle per-foot cost of the particular type of plant.

more structure to be shifted across types than do further increases in this divergence. The user-adjustable default fraction of buried structure that is "at risk" to be converted to aerial structure based on adverse local life-cycle costs is 75 percent.

6.3. Distribution Module

6.3.1. Treatment of Main Clusters

HM 5.0a lays distribution plant directly over the rectangular areas where customer clusters are located. This plant extends from the SAI location (or locations) to the customer premises in the cluster. The basic distribution configuration employed by HM 5.0a for the main clusters is a "grid" topology, in which tapering backbone cables run north and south from the SAI(s), while branch cables extend east and west from the backbone cables past the individual subscriber locations.[46] The backbone cables terminate one lot depth inside the north and south boundaries of the rectangle. The branch cables run to within one lot width of the east and west sides of the rectangle.

The Module performs a test to ensure that the longest combined backbone and distribution cable run does not exceed a user-adjustable maximum copper distance whose default value is 18,000 feet. If the maximum distance would otherwise be exceeded, the model will extend fiber subfeeder "connecting cables" from the centroid of the cluster to two or more DLC RTs (and adjacent SAIs) positioned to ensure the maximum distance is not exceeded. The number of RT/SAI locations is determined by separately checking that the backbone and branch cable lengths do not exceed a fraction of the maximum distance calculated from the aspect ratio of the cluster shape, and splitting the cluster area in either or both dimensions to create the necessary two or more subareas.

Main clusters with total areas less than 0.03 square miles and line densities greater than 30,000 lines per square mile are identified as consisting of high-rise buildings, and accorded special treatment appropriate for high rises.

This high-rise test identifies cases in which a serving area is very small, but its line density is so high as to be incompatible with any explanation other than vertical "stacking" of the customer locations. In such cases, the model assumes the distribution cable required to serve the main cluster consists of riser cable inside the high rise building, and that the SAI required for service is located in the basement of such a building. The number of floors in the high rise buildings is estimated by dividing the occupied building space by the area of the main cluster, reduced to account for streets and sidewalks.[47] The occupied building space in square feet is calculated as follows:

[46] The coordinate system used in the HM 5.0a to denote "north," "south," "east" and "west" is the Vertical and Horizontal (V & H) system that is standard in the telephone industry. These coordinates are internally consistent, but differ slightly from "true" north, south, east or west.

[47] The reduction in main cluster area for urban streets and sidewalks, expressed as a fraction; is user-adjustable with a default value of 0.2.

occupied space = 1,500 * # households + 200 * # employees.

For "regular" serving areas that do not meet the high-rise test, the model computes the plot size per customer location by dividing the effective area of the main cluster by the number of customer locations in the main cluster, as stated above. The model assumes that each customer plot is twice as deep as its frontage.

However, a refinement to this calculation is required to account for the fact that many households occupy dwelling units that cannot be characterized as single family detached homes. Likewise, structures occupied by business establishments may range from small single-tenant stores on small lots to large, multi-floor buildings (high-rise buildings are treated separately). A residence and a business methodology are adopted to represent more realistically the actual situations that may occur.

For residences, the Census database supplied by PNR identifies the number of households located in various types of buildings. HM 5.0a assumes that the space occupied by residences other than single-family detached units is half that of detached homes, and accordingly reduces the number of customer locations in calculating the effective plot size of detached homes. This reduction represents more adequately the space (including the actual living quarters, shared facilities, parking lots, and other area around buildings) that households in multi-dwelling units occupy relative to a detached single-family home. The reduction in effective customer locations is made before calculating the lot size in the manner described above. The intent is to calculate the effective lot size that detached homes would have in the main cluster, and lay out the distribution cables accordingly. The model assumes the grid pattern of cables continues throughout the areas where multi-tenant units are located; thus, there is no additional efficiency associated with serving such premises.

The assumed reduction in effective households is conservative because the model assumes multi-tenant units displace one-half of a regular-sized lot. Thus, the model will consequently underestimate the effective lot size of detached homes because it is counting too high a number of equivalent customer locations. This underestimate of effective lot size causes more lots to be assumed, and more distribution plant to be placed, than actually is necessary to serve this area.

6.3.2. Treatment of Outlier Clusters

Outlier clusters, each consisting of one or more customer locations, are served in HM 5.0a by the nearest main cluster. A main cluster and its subtending outlier clusters together constitute a serving area.

Outliers are connected to the main cluster by copper road cables extending from the centroid of the main cluster to the centroid of the outlier. A given outlier may be directly connected to the main cluster, in which case it is labeled a "first order" outlier, or it may be connected to another outlier which in turn is connected directly to the main cluster or another outlier. Such connections are depicted in Figure 5. Outliers that are not directly connected to the main cluster are considered to be "higher order" outliers.

Fiber feeder is extended to any main cluster that has at least one outlier cluster. The road cables to the first order outliers extend from the point at which the fiber feeder terminates in the main cluster. If the right-angle route distance from the main cluster to the farthest customer location in a first order outlier is less than a user-adjustable distance parameter whose default value is 18,000 feet, the road cable carries an ordinary analog voice signal, and is called "subscriber road cable." If the farthest customer in an outlier is more than the default distance from the main cluster, or the outlier is a higher order outlier, the cable carries a digital T1 format signal to a remote T1 terminal at the centroid of the outlier, and is served by "T1 road cable." From the T1 RT, copper cables carrying analog signals extend the remainder of the way to the customer locations within the outlier.

A T1 road cable contains copper pairs, and supports T1 signals used to provide digital connections between the fiber DLC remote terminals located at the centroid of the main cluster and subsidiary remote T1 terminals located at the centroid of each outlier cluster. The model assumes conventional T1 transmission with a user-adjustable 32 dB repeater spacing.

In HM 5.0a the cables serving subscribers from the remote terminals are assumed to be different than those that carry the T1 signals to the remote terminals. The total investment calculated for the T1 system includes the cost of the T1 interfaces in the main cluster's DLC remote terminal.

6.3.3. Customer Drop Arrangement

No matter whether a customer is located in a main cluster or outlier cluster, the distribution arrangement at the customer's premises is similar. At a point close to the customer's location, a splice and block terminal are installed to connect a drop cable containing several wire pairs from the distribution cable to an aerial or buried drop to the NID located on the wall of the premises.

6.3.4. Investment Cap to Reflect Potential Wireless Technologies

As requested in the FCC's FNPRM, the HM 5.0a permits the specification of a user-adjustable cap on the model's relevant wireline investments to reflect potentially more economical wireless distribution technologies.[48] In the HM 5.0a this cap, if invoked by the user, is implemented by placing a ceiling on the per-line investments computed in the Distribution module (i.e., NID, drop, terminal and splice, distribution cable and structure, SAI, and DLC RT) that would be replaced by the wireless system.[49]

[48] It is unclear whether such systems exist, whether their costs can be modeled accurately across all demographic and terrain situations, and whether these systems can meet the FCC's criteria for supported universal service.

[49] It is assumed that the cost of the remote terminal electronics for the fiber feeder facilities serving the wireless radio sites would be included in the wireless system cost.

The optional cap calculation considers the cost of two different wireless systems: a "point-point" system serving customers on a one-one basis, and a "broadcast" system serving a number of customers from a shared base station. The point-point cost is assumed to be a fixed amount per line served; the broadcast system cost is structured as a fixed base station cost serving up to a given maximum number of customers, with the cost of the base station distributed among the number of customers that use it, plus a per-line cost of the radio terminal equipment at each customers' premises. Generally, the broadcast system is more expensive than the point-point system for a few lines in a serving area, but less expensive if the system is loaded to a substantial portion of its maximum capacity. The Model compares the cost of the two wireless systems to each other for a given serving area, then compares the cost of the lower-cost system to the wireline cost. If the most economical wireless system's cost is lower, the Model zeroes out the cost of the wireline distribution components for that serving area, and substitutes the cost of the wireless distribution system, while retaining the feeder portion of the wireline network.

6.3.5. Determination of Feeder Technology

Because it must calculate all of the outside plant distances, to determine the kind of road cable required, the Distribution Module also determines whether copper or fiber feeder and subfeeder are utilized for a given serving area. If fiber feeder and subfeeder are used, these extend from the wire center to the main cluster centroid. The subfeeder terminates at one or more DLC RTs and adjacent SAIs -- located to ensure that the remaining distribution cable lengths do not exceed the user-adjustable maximum analog copper length. In all cases, copper distribution cable is used to link SAIs to customer premises. The decision whether to use fiber feeder depends on whether any of the following conditions are met.

a) The total feeder and subfeeder distance from the wire center to the main cluster centroid is greater than the user-adjustable Copper Feeder Max Distance value, whose default is 9,000 ft.

b) A life-cycle cost analysis of fiber versus copper feeder on the route shows that fiber is more economical.[50]

c) The longest distribution cable run from the wire center to the farthest corner of a main cluster is greater than a user-input maximum analog copper distance, whose default value is 18,000 ft.

d) There is at least one outlier cluster subtending the main cluster.

e) The wireless investment cap is invoked and leads to the conclusion that one of the two wireless systems is the least-cost solution for the serving area.[51].

[50] The life-cycle costs of fiber versus copper feeder are computed using the same methodology, as described earlier, to calculate the life-cycle costs of outside plant placements on different structure types.

6.3.6. "Steering" Feeder Routes

In HM 5.0a the user may elect to have the Feeder Module "steer" feeder routes toward the preponderance of main clusters within a quadrant. The model computes an angular offset from the cardinal default values of 0º, 90º, 180º or 270º by weighting each main cluster's angular offset coordinate by its radial distance from the wire center location, and then determining the weighted average angular displacement. When feeder cable is steered in this fashion, the Feeder Module also applies a route-to-airline (R/A) distance multiplier. The value of this multiplier may be specified by the user within an allowed range of R/A values. Subfeeder cables branch perpendicularly off the main feeder route toward main clusters. This branching is perpendicular both when feeder routes go in the cardinal compass point directions, as well as when the feeder is steered at an angular offset from these cardinal directions. Alternatively, the user may elect to "turn off" feeder route steering and have the Module calculate feeder distances using "right angle routing" in the four cardinal compass point directions -- as employed in HM 4.0.

6.3.7. Calculation of Distribution Investments

The model uses the customer location and cluster data, including cluster sizes and locations, number of lines, and lines density; and applies these demographic and architectural considerations to determine the total distribution distances involved. It then estimates the investment in distribution cable, supporting structures, terminals and splices, drops, NIDs, and SAIs.

In calculating these investments, the model requires a number of data elements which are provided to it through adjustable user inputs. These include cable sizing factors, the amount of structure sharing with other utilities, the relative mix of aerial, buried, and underground facilities, the unit material and installation costs of the various network components, the demographic factors identified in Section 6.1 above, and factors relating difficult terrain characteristics that may increase installation costs.

Appendix B defines each user input and the default value(s) for that input as set by the model developers. The set of inputs pertinent to the distribution calculations are inputs B1 through B45 (basic distribution and drop components), B58 through B69 (DLC components), B180 (structure sharing), and B197 through B201 (excavation and restoral activity frequency and costs), in Appendix B.

Three sets of the input parameters bear special attention. The first is the set of cable sizing factors appearing as item B18 in Appendix B. Sizing factors are intended to provide reserve capacity above and beyond the lines requirement determined by the model. If, for instance, a given cable segment must serve 75 lines and the sizing factor set by the model is 0.50, then the target cable size determined by the model is 75/0.5, or 150. However, cables are available only in discrete sizes, as shown in Item B9 in

[51] When wireless is used, it is assumed that a minimum of four fibers must be used to connect the radio sites to the wire center.

Appendix B. The model selects the cable size at or most closely above the minimum size calculated. In this example, this corresponds to a 200 pair cable. Thus, the achieved fill is 75/200, or 0.375. Generally, the average achieved distribution fill is significantly less than is indicated by the raw cable sizing factors shown in Item B18. The Model outputs display this average actually achieved fill both at the SAI and at the MDF.

Second, as discussed earlier, the HAI Model assumes that forward-looking practices of efficient telephone companies and other utilities will involve substantial structure sharing. The default levels of structure sharing assumed in HM 5.0a, stated as the percentage of total structure costs assigned to the telephone company, are shown in Item B180 of Appendix B. In HM 5.0a the amount of structure sharing depends both on the type of structure -- poles and trenching -- and the density zone. HM 5.0a assumes, conservatively, that there is no sharing of conduit in underground installations.

Finally, HM 5.0a offers an optional cap on distribution investment as discussed, above. This cap, enabled by Parameter B41, compares the total per-line wireline distribution costs for all distribution components to the cost of two types of wireless systems. One system's per-line cost is expressed by B42; the other system's cost is parameterized by a base station cost, B43, maximum customers served by a base station, B45, and per-line radio system equipment cost, B44.

6.3.8. Calculation of SAI and DLC Investments

The SAI in each serving area provides an interface between the feeder and distribution facilities. Each SAI consists of a cabinet, including suitable physical mounting, and a simple passive cross connect. In the case of fiber feeder there is an adjacent DLC remote terminal. SAI investment is determined by the number of distribution and feeder pairs required to be served. The model equips multiple SAIs if the pair requirement exceeds the maximum SAI capacity.

Urban areas normally have feeder cable running directly into the basement of large buildings, rather than interfacing at an SAI outside of the building. In such cases, the SAI, located in the building, is significantly less expensive than the outdoor SAI. This type of interface consists of a plywood backboard and inexpensive "punch-down blocks," rather than the heavy steel weatherproof outside terminals found in less urban areas. HM 5.0a thus differentiates between outdoor and indoor SAIs, the former being the normal case, and the latter being used when a serving area is identified as a high-rise building.

The Distribution Module sizes and calculates the investment in the SAIs required in each serving area based on the number of distribution and feeder pairs required to serve both the main and outlier clusters and the urban/non-urban characteristic of the serving area. The pertinent input parameter for the SAI is identified as B38 in Appendix B. It is the installed investment in an SAI, stated as a function of the number of distribution and feeder pairs served by the SAI. The model equips each serving area with one or more SAIs. The number required is determined by comparing the total "in" and "out" lines demand to 7,200, which is the maximum number of pairs that can be supported by a single SAI.

A given serving area may be served by either fiber feeder or copper feeder. When fiber feeder is used, one of two types of DLC equipment is selected. The first is designated "High Density" DLC, and is GR-303 compliant."[52] The second is designated "Low Density" DLC, and is also GR-303 compliant. The choice between these two types is determined for each serving area. If the number of lines is below a threshold value, "low density" DLC is used; above that threshold, "high density" DLC is assumed. The threshold is user-adjustable, with a default value of 480 lines.

The investment in DLC equipment, when it is used, is calculated in the Distribution Module. The parameters involved in this calculation are identified as Items B58 through B69 in Appendix B. For either type of DLC system, low density or high density, the investment is calculated based on user-adjustable amounts for site and powering (B58), for common equipment (B61), and for channel units (B62). Other inputs in the range of B59-B69 specify, for example, the number of fiber strands per RT, the maximum initial lines that can be served by the DLC, the number, size and additional common equipment requirement of additional line increments, and the capacity and cost of plug-in cards for POTS and coin service. The DLCs are equipped by the model with line cards of the type required to provide the appropriate grade of service on the analog and digital (T1) pairs fed off of the DLC – at the distances implied by the structure of the main and outlier clusters.

6.3.9. Calculation of Drop Investments

HM 5.0a computes a weighted average drop investment in each density zone on both a per-drop and per-pair basis. The model uses the detailed household type and business line information contained in the demographic database to compute the total drop investment in each serving area. The total drop investment is applied to the sum of all households in single family attached and detached dwellings, mobile homes and "other" dwelling types, all two- and four-household dwellings, and all single-line businesses. The per-pair drop investment applies to the remaining business lines, the adjusted private line total, and public lines, as well as to all households in multi-unit buildings containing five or more households.

6.4. Feeder Module

6.4.1. Overview

The Distribution Module produces as inputs to the Feeder Module the main feeder and subfeeder cable distances for each serving area. The Feeder Module uses these inputs to calculate the investment in feeder plant.

As seen earlier in Figure 1, feeder cable begins at the wire center and ends at the SAI located within each serving area. Figure 6 displays the basic main feeder and subfeeder

[52] GR-303 (which is also called "TR-303" in earlier documents that are still in common use in the industry) is a Bellcore requirements document dealing with interfacing a DLC system with an end office switch.

architecture assumed in the model.[53] A key difference between HM 5.0a, compared to HM 4.0, is that in HM 5.0a the unit of population served by a given feeder and subfeeder cable combination is the main cluster and its subtending outlier clusters, rather than a CBG. Note that since a given main cluster can be surrounded by outlier clusters and/or areas with no population, there may be gaps between the main clusters, as shown in the drawing. In areas of dense population, they are, however, likely to be contiguous.

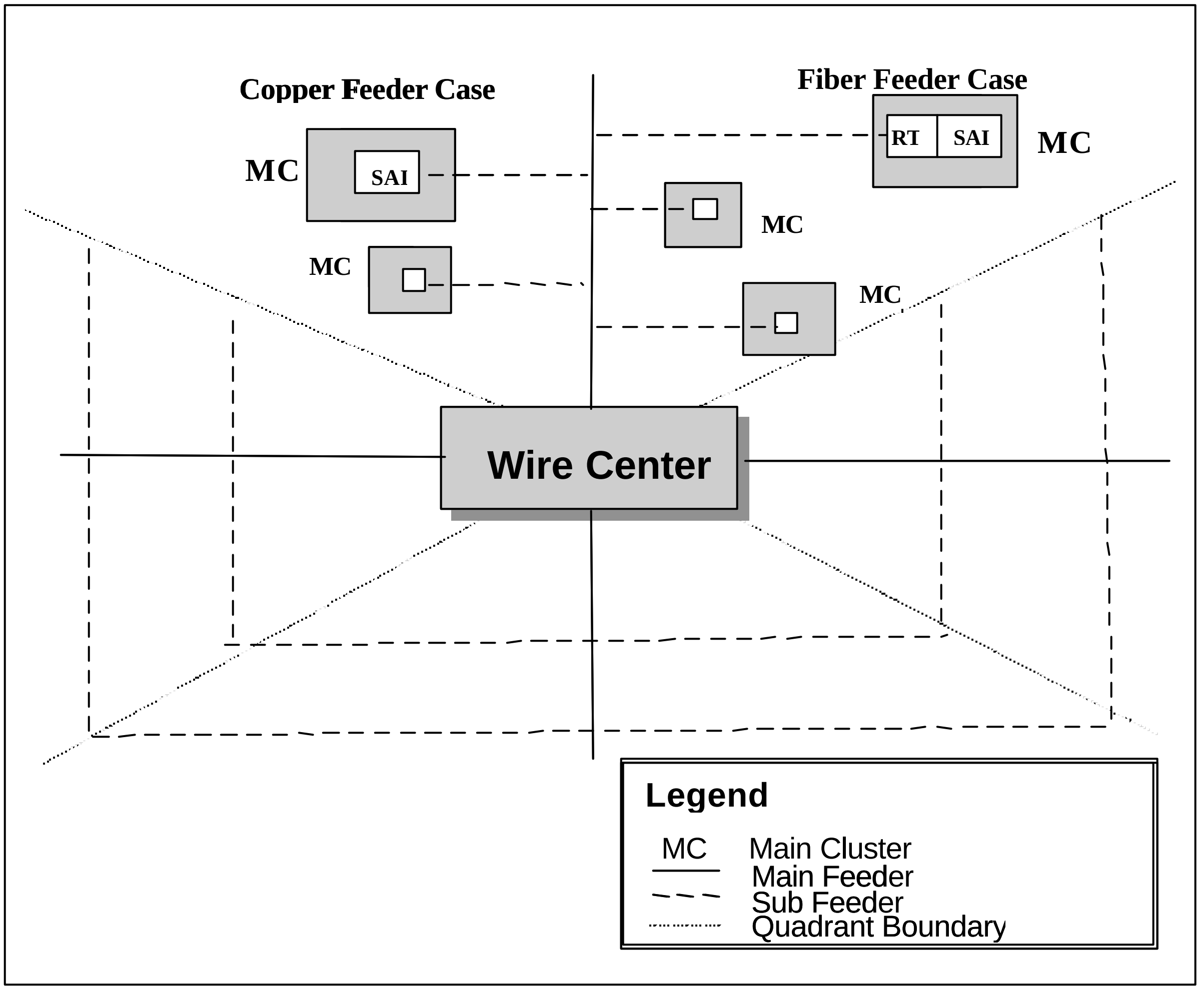

Figure 6 Feeder Architecture

As many as four main feeder routes may terminate at each wire center. Each feeder route serves one quadrant of the wire center's service area, and quadrant boundaries form

[53] As discussed previously, subfeeder may be linked at the main cluster centroid to connecting cables that run to two or more DLC RTs located at other points within the main cluster. Such connecting cables are also classified as feeder cable by the model, since telephone companies classify all cable on the wire center side of the DLC RT as feeder cable.

angles of $\pm 45°$ with the main feeder routes.[54] Each main cluster is served by the main feeder route associated with the quadrant containing the centroid of the main cluster. To reach each cluster, a subfeeder branches from the main feeder at right angles and extends to an SAI within the cluster. As described in Section 6.3.6 on the Distribution Module, each of the four main feeders may, at the user's option, be "steered" towards the preponderance of main cluster locations within the quadrant in question, and a route-to-air multiplier applied to the "steered" feeder route distance.

The main feeder cable sizes for both fiber and copper facilities are a function of the total number of lines in each serving area, and the feeder sizing factor for those serving areas. Feeder cable sizes range from 100 to 4200 pair cable for copper, and from 12 to 216 strands for fiber. Multiple cables are installed along feeder routes when the maximum size of a single cable is exceeded. Main feeder routes taper as they pass the splice points at which subfeeder branches off to connect to the individual serving areas. Thus, the main feeder cable sizes generally decrease in increments as the distance from the wire center increases.

Both copper and fiber feeder cable may appear on a single main feeder route to provide connections to different serving areas. If they do, they share most structure, including poles, manholes and trenching. Copper and fiber cables are assumed not, however, to share conduit when they do follow the same route.

6.4.2. Development of Feeder Investments

6.4.2.1. Calculating Main Feeder and Subfeeder Distances

As was shown in Figure 6, main feeder routes extend from the wire center in as many as four directions.[55] Subfeeder cables branch from the main feeder at right angles, giving rise to the familiar tree topology of feeder routes. The points at which subfeeders branch off the main feeder delineate main feeder segments, which are the portions of main feeder cable between two branch points.[56]

The centers (centroids) of the main clusters may fall in any of the four feeder route quadrants. As shown in Figure 7, a set of parameters, including the quadrant, airline (radial) distance and angles (omega and alpha), locate the main cluster with respect to the serving wire center. With this information, HM 5.0a applies straightforward

[54] Because HM 5.0a uses V&H coordinates to locate clusters and wire centers, feeder routes are assumed to emanate from the wire center along the V&H axes. These axes are rotated slightly clockwise relative to latitude and longitude axes.

[55] If no cluster centroids fall within a given quadrant of a wire center, no feeder route will be provided in that quadrant.

[56] Splicing is required where the main feeder branches into subfeeder. The cost of splicing, including material, equipment, and labor, is included with the cost of the cable assumed in the model.

trigonometric calculations to compute main feeder and subfeeder distances.[57] The model computes sufficient subfeeder cable to connect the main feeder route to the centroid of each main cluster. Copper feeder cable always terminates at an SAI at the centroid of the main cluster. If the model calls for fiber feeder, the subfeeder terminates at an RT at the centroid, adjacent to an SAI.

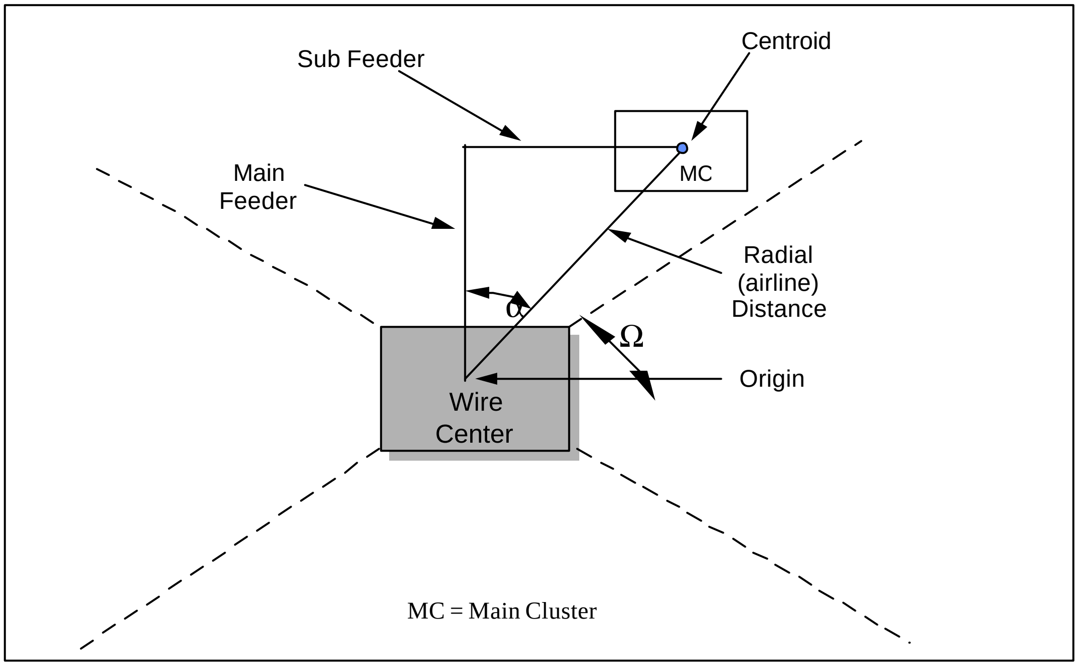

Figure 7 Determination of Cluster Locations and Distances

The criteria by which the Model decides if a main cluster is served by copper or fiber feeder cable have been discussed in the Distribution Module description, since this decision is made there.

Figure 8 demonstrates that multiple serving areas share capacity on certain segments of the main feeder route. Segments located closer to the wire center require more capacity than segments near the periphery. HM 5.0a addresses this need by tapering the main feeder facilities as the distance from the wire center increases. Thus, it must determine the various "segment distances," shown as S-1, S-2, ..., in Figure 8, so it can size the cable in each segment. The segment distances along a main route are calculated in two steps. First, the main clusters are sorted so they appear in the order of increasing distance along the main route. Segment distances are then calculated as the difference between the main feeder distances of adjacent main clusters.

[57] In rural areas where a feeder route may serve only one or two main clusters, this rectilinear routing assumption is extremely conservative relative to the efficiencies that could be realized using a steered feeder routing.

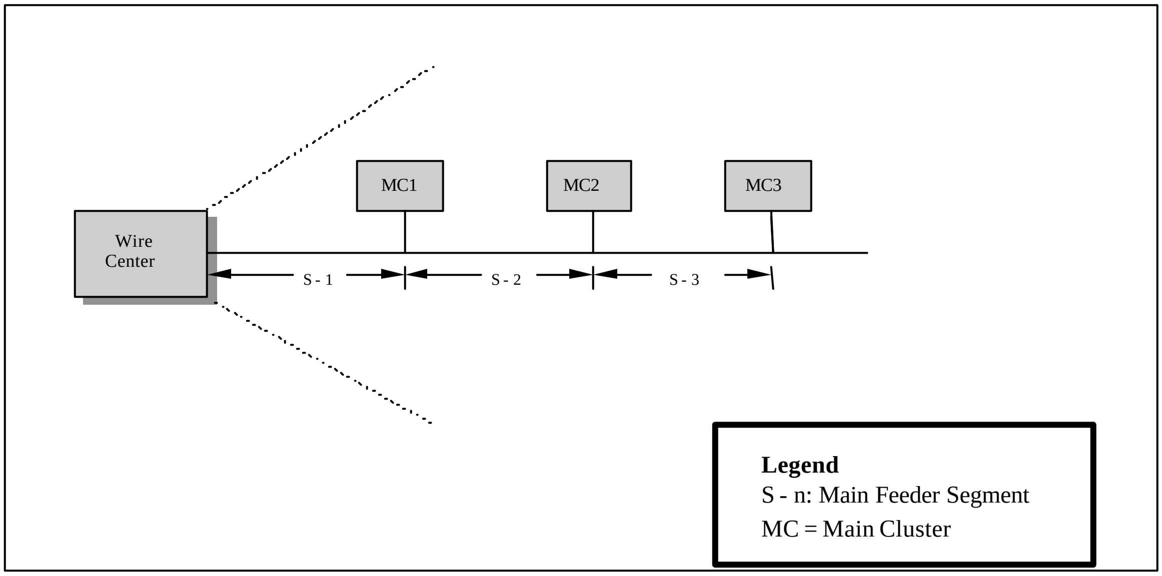

Figure 8 Main Feeder Segmentation

6.4.2.2. Copper and Fiber Subfeeder Cable Sizing

Sizing copper subfeeder cable for individual serving areas is a function of two parameters: the total number of lines within the serving area and the copper feeder sizing factor. To select the appropriate cable size, the required line capacity is computed by dividing the total number of lines in the serving area by the sizing factor. The model then chooses the smallest cable size that meets or exceeds this quotient. For instance, if the number of lines is 200 and the sizing factor is 0.80, the next cable size larger than 200/0.80 is selected. Since 200/0.80 equals 250, the 400 pair cable is selected. As with distribution cable, this may lower substantially the average effective fill compared to the input value entered. Multiple cables are used in cases where the maximum cable size is surpassed.

The number of optical fibers needed to serve a given serving area is calculated by multiplying the number of DLC RTs in that serving area by the number of strands per RT. The strands per RT is a user-adjustable quantity, with a default value of four.[58] In the subfeeder to a particular serving area, the model chooses the smallest optical fiber cable size that meets or exceeds the required number of strands, with a minimum cable size of twelve fiber strands. In the main feeder, the fiber cable on each segment is sized to meet the aggregate demand of serving areas beyond that segment, taking a user-adjustable fiber strand fill factor into account.

6.4.2.3. Main Feeder Segment Sizing

[58] Because a DLC terminal requires a minimum of two fibers, one for each direction of transmission, the HM 5.0a default of four fibers provides complete redundancy.

Each segment in the main feeder is sized to meet the requirements of all the serving areas located past the segment. For example, in Figure 8, segment 1 is sized with adequate capacity for serving areas 1, 2, and 3. Segment 3 will be sized with less capacity than segment 1 since it serves only serving area 3. Thus, the individual cable requirements for serving areas at and beyond the end of a particular main feeder segment are aggregated to determine the required cable size for that main feeder segment. When the maximum cable size is exceeded on a given segment, multiple cables are installed.

6.4.2.4. Structure Investments

The fraction of aerial, buried and underground plant may be set separately for all density ranges and for each feeder cable type, copper or optical fiber. Based on these fractions, the distances involved, and the cost of various structure components, the Feeder Module calculates the investment in feeder structure.

In addition to the sharing of structure between telephone companies and other utilities, there are two other forms of structure sharing relevant to feeder plant. First, with the exception of conduit, structure is shared between copper and fiber feeder cables along main feeder routes. Second, structure is shared between feeder and interoffice facilities. A detailed discussion of the latter type of sharing is presented in the interoffice section of this document.

6.4.2.5. Allocation of Main Feeder Investments

All the feeder facility investments are computed on a per-serving area basis. To do this, it is necessary to assign the appropriate amount of investment in each segment of the main feeder route to the individual serving areas that are served by that segment. The portion of a main feeder segment investment assigned to a serving area whose lines are carried on that segment is computed using the ratio of lines in that serving area to total number of lines in all serving areas carried on that main feeder segment. This is done separately for the copper and fiber feeder that may coexist on a given route.

6.4.2.6. Relevant Input Parameters

The set of user inputs and default values used in feeder calculations appear as inputs B46-B57 and B70-B71, described in Appendix B. The Feeder Module also calculates terrain impacts using inputs B20-B23. It allows the user to enable feeder steering and to set the route/air ratio using B26 and B27, respectively; can override the calculated aspect ratio of the main cluster and thereby force main clusters to be square using B27a; and specifies excavation and restoration costs (jointly with distribution) using B197 through B201.

6.5. Switching and Interoffice Module

6.5.1. Overview

This Module produces network investment estimates in the following categories:

a) *Switching and wire center investment* -- This category includes investment in local and tandem switches, along with associated investments in wire center facilities, including buildings, land, power systems and distributing frames.

b) *Signaling network investment* -- This includes investment in STPs, SCPs and signaling links.

c) *Transport investment* -- This category consists of investment in transmission systems supporting local interoffice (common and direct) trunks, intraLATA toll trunks (common and direct) and access trunks (common and dedicated).

d) *Operator Systems investment* -- This includes investments in operator systems positions and operator tandems.

6.5.2. Description of Inputs and Assumptions

For the Switching and Interoffice Module to compute required switching and transmission investments, it requires as inputs total line counts for each wire center, distances between switches, and traffic peakedness assumptions, as well as inputs describing the distribution of total traffic among local intraoffice, local interoffice, intraLATA toll, interexchange access and operator services. This module takes as data inputs minutes and calling volumes from ARMIS, overall line counts obtained from the PNR database for the serving areas belonging to that wire center, and wire center locations and interoffice distances from the distance file for the calculation of transmission facilities investments.[59] It also requires many user-adjustable input assumptions. The set of user inputs and default values described in Appendix B and used in various phases of the module include:

- B74-B85 and B176-B177, for end office switching;
- B86-B91, for the wire center in which the end office switches and tandems are housed.
- B107-B130, for interoffice transmission terminals, media and structures;
- B143-B149, for tandem switching;
- B150-B163, for interoffice signaling; and
- B164-B167, for operator services and public telephone.

In addition, various traffic parameters are provided by inputs B92-B106, and miscellaneous parameters, such as the percent of traffic that requires operator assistance, percent that is interoffice, and percent that is routed directly between end offices, are provided by B131-B142. Finally, there is a set of inputs representing surrogate per-line investment in various switching and signaling equipment components by small

[59] HM 5.0a includes a set of interoffice distance calculations produced from wire center location information from Bellcore's Local Exchange Routing Guide (LERG) and from NECA Tariff 4.

independent telephone companies ("ICOs"), appearing as B168-B175. These are used in lieu of the results that would be calculated by the model for small ICOs with less than fifty wire centers, and better reflect these ICOs' typical practice of purchasing usage of such components from larger LECs.

Many of the calculations in the Switching and Interoffice module rely on traffic assumptions suggested in Bellcore documents.[60] These inputs, which the user may alter, assume 1.3 busy hour call attempts ("BHCA") per residential line and 3.5 BHCA per business line. Total busy hour usage is then determined based on published Dial Equipment Minutes ("DEM") information. Other inputs, which may be changed by the user, specify the fraction of traffic that is interoffice, the fraction of traffic that flows to operator services, the local fraction of overall traffic, as well as breakouts between direct-routed and tandem-routed local, intraLATA toll, and access traffic.

6.5.3. Explanation of Calculations

The following sections describe the calculations used to generate investments associated with switching, wire centers, interoffice transport, signaling and operator systems functions.

6.5.3.1. End Office Switching Investments

The Module places at least one end office switch in each wire center. It sizes the switches placed in the wire center by adding up all the switched lines in the CBGs served by the wire center, applying a user-adjustable administrative line fill factor, and then comparing the resulting line total to the maximum allowable switch line size. The maximum switch line size parameter is user-adjustable; its default setting is 80,000 lines plus trunks. The model will equip the wire center with a single switch if the number of ports (lines and trunks) served by the wire center is no greater than a user-adjustable maximum size – that defaults to 80,000. If a wire center must serve, say, 90,000 ports, the model will compute the investment required for two 45,000-port switches.[61]

The wire center module performs two additional capacity checks. First, it compares the BHCA produced by the mix of lines served by each switch with a user-adjustable processor capacity (default set at a maximum of up to 600,000 BHCA, depending on the size of the switch) to determine whether the switch is line-limited or processor real-time-limited. In making this calculation, the per-line BHCA input is multiplied by a user-adjustable processor feature loading multiplier. The default value of the feature loading

[60] Bell Communications Research, *LATA Switching Systems Generic Requirements, Section 17: Traffic Capacity and Environment*, TR-TSY-000517, Issue 3, March 1989.

[61] If multiple switches are required in the wire center, they are sized equally to allow for maximum growth on each switch.

multiplier varies between 1.2 and 2.0, depending on business line penetration,[62] to reflect additional processing loads caused by features.

Second, the module compares the offered traffic, expressed as BHCCS, with a user-adjustable traffic capacity limit (default set at a maximum of up to 1,800,000 BHCCS, depending on the size of the switch). To make this comparison, the per-line traffic estimate calculated from the reported DEMs is multiplied by a user-adjustable holding time multiplier, which can be separately set for business and residence customers. Default values of the business and residential holding time multipliers are 1. They can be increased above that value to reflect the incidence of calls that have longer than normal holding times, and thus increase the traffic load on the switch. A example could be heavy Internet access via the voice network. If either of these processor or traffic capacity tests leads to the corresponding limit being exceeded, the model will compute the investment required for additional switches, each serving an equal number of total lines.

HM 5.0a is capable of engineering and costing end office switching systems comprised of explicit combinations of host, remote and standalone switches. But, because accurate data on the purchase prices of a portfolio of host, remote and standalone switches of varying capacities may not be available to the user, the HM 5.0a Switching and Interoffice Module defaults to computing end office switching investments using input values that average per-line investments over an efficient portfolio of host, remote, and standalone end office switches. Thus, the model's calculated end office switching investments and corresponding costs subsume either explicitly specified switch technologies on a wire center by wire center basis, or a blended overall efficient mixture of host, remote, and standalone switches within the modeled network.

If the user selects the explicit host, remote, standalone option, the user must specify for each wire center whether the housed switches are hosts or remotes, as well as assign correspondences between hosts and remotes. The model will designate all remaining wire centers as housing standalone switches. The model then places the hosts and their subtending remotes on SONET rings separate from the interoffice rings discussed below. Host switches may therefore appear on two rings -- their local host/remote ring, and (if the host directly serves more than the user-specified small office line limit) a larger interoffice ring interconnecting end offices and tandem locations.

The model sizes the host-remote rings to accommodate host-remote umbilical trunk and control link requirements. It then computes investment in SONET add/drop multiplexers ("ADMs") and digital cross connects ("DCSs") for the host/remote ring and calculates the average ADM and DCS investment per line for all lines in the system. The host interoffice calculations also are adjusted to account for the increased trunk and signaling capacity requirements imposed by the remotes served by the host.

[62] The multiplier is set at 1.2 up to a business penetration (i.e., % business lines) threshold set by the user, then increases linearly to 2.0 at 100% business penetration.

End office switching investment calculations obtain common equipment and per-line investments for all three switch types from a user-adjustable investment table, which contains end office investment entries for both large and small LECs. Once the model computes investments for each switch in a host/remote system, it calculates the average investment per line for all of the lines in the system.

In more detail, the costing process is as follows. When the host-remote option is selected, switching curves that correspond to host, remote and standalone switches are used to determine the appropriate switching investment. These new switching curves incorporate a fixed plus variable investment per line for each switch type. It is recognized that there are large and small host and standalone switch technologies, and that remotes are available in multiple line sizes. Remote switches cause incremental variable investments primarily associated with the umbilical trunk ports necessary to carry traffic originating and terminating on the remote lines to the host switch. The user adjustable fixed and variable investments for host, standalone and remote switches have been scaled accordingly. In accordance with the FCC's Public Notice guidelines, the cost of an entire switching system consisting of a host and its associated remotes, is allocated evenly over all lines served by the host-remote configuration.

In default mode, the model assumes a blended configuration of switch technologies. The switching cost curves for this blended configuration were developed using typical per-line prices paid by BOCs, GTE and other independents as reported in the Northern Business Information ("NBI") publication, "U.S. Central Office Equipment Market: 1995 Database."[63] In addition, public line and switch data from the ARMIS 43-07 and responses to the USF NOI data request from 1994 are also employed.

The module uses a large telephone company switching investment curve that is based on the RBOC and GTE average switching costs per line reported in the NBI study. These two switching cost points were paired with the average sizes of current RBOC and GTE switches derived from 1995 ARMIS 43-07 line and switch data. A third cost point for large switches of 80,000 ports was developed from other industry sources. A logarithmic curve was then fit to these data using least-squares regression. As demonstrated in Figure 9, this functional form fits the data very closely.

The 1993 USF NOI (Universal Service Fund Notice of Inquiry) data was used to estimate an average line size for small LEC switches. A 1995 average line size was estimated by assuming the ICOs have experienced growth in average lines per switch between 1993 and 1995 similar to that experienced by GTE. The value on the large LEC curve corresponding to this 1995 small LEC average line size was compared to the ICO per line value from the NBI report. This produced a 1.7 factor which was applied to the constant term in the logarithmic functional form to produce a curve of identical shape, but shifted upward by $173 per line compared to the large LEC curve. The "slope" multiplier

[63] Northern Business Information study: U.S. Central Office Equipment Market -- 1995, McGraw-Hill, New York , 1996

(default of -14.922 in Figure 9) and the constant term (default of 242.73 in Figure 9 for large LECs and default of 416.11 for small ICOs) are user adjustable.

The per-line investment figures from the NBI study are for the entire end office switch, including trunk ports. The investment figures are then reduced by $16 per line to remove trunk port investment based on NBI's implicit line to trunk ratio of 6:1. The actual number of trunks per wire center is calculated in the transport calculation, and the port investments for these trunks are then added back into the switching investments. Figure 9 shows the switching investment curves for large LECs resulting from this methodology.

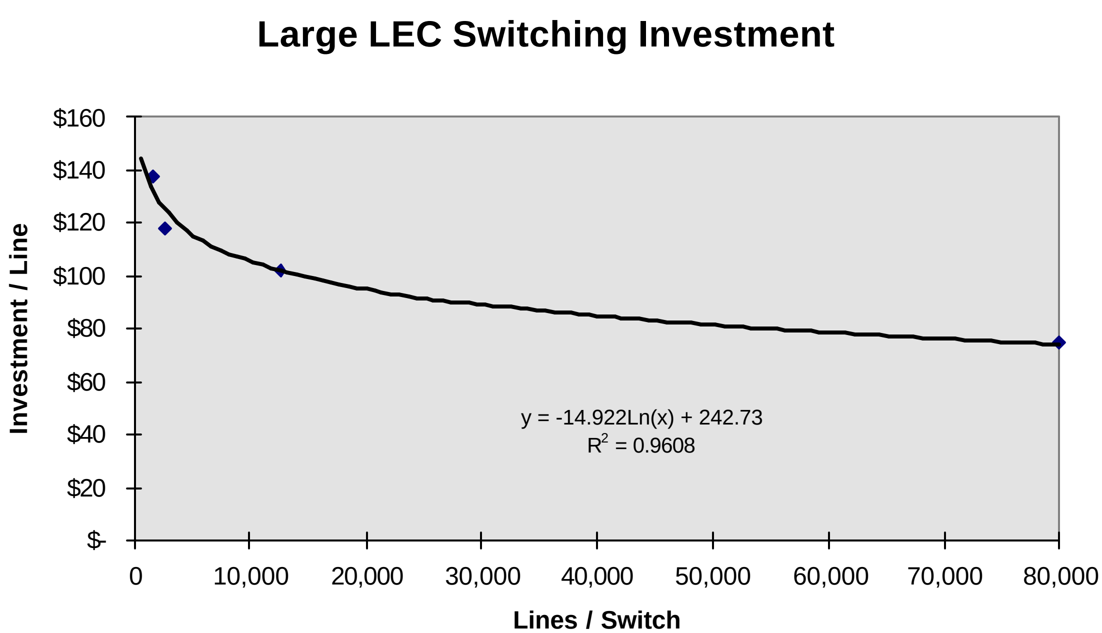

Figure 9 Blended Switch Investment Curve

Wire center investments required to support end office and tandem switches are based on assumptions regarding the room size required to house a switch (for end offices, this size varies according to the line sizes of the switch), construction costs, lot sizes, land acquisition costs and investment in power systems and distributing frames.

The model computes required wire center investments separately for each switch. For wire centers housing multiple end office switches, the wire center investment calculation adds switch rooms to house each additional switch.

6.5.3.2. Transport Investments

The traffic and routing inputs listed previously, along with the total mix of access lines served by each switch, form the basis for the model's transport calculations. The model determines the overall breakdown of traffic per subscriber according to the given traffic assumptions and computes the numbers of trunks required to carry this traffic. These calculations are based on the fractions of total traffic assumed for interoffice, local direct routing, local tandem routing, intraLATA direct and tandem routing, and access dedicated and tandem routing. These traffic fractions are applied to the total traffic generated in each wire center according to the mix of business and residential lines and appropriate per-line offered load assumptions. The model computes the total offered load per wire center for various classes of trunks – e.g., local direct-routed trunks. It then compares the offered load for a trunk class to a traffic engineering threshold. If the offered load exceeds the threshold, the computed number of trunks is just the quotient of the total offered load divided by the user-specified maximum trunk occupancy (default = 27.5 CCS). If the traffic load is less than the threshold, the model obtains the correct number of trunks using Erlang B assumptions and 1% blocking from a lookup table.

The traffic engineering threshold value is determined from the user-specified maximum occupancy value through another table lookup which determines the number of trunks that will carry the specified maximum occupancy at 1% blocking. The threshold value is the product of the input maximum occupancy and the corresponding number of trunks. The user may enter maximum occupancies between 17.5 and 30 CCS.

HM 5.0a assumes that, with some exceptions, all interoffice facilities take the form of a set of interconnected Synchronous Optical Network (SONET) fiber rings. It uses a program written in Visual Basic for Applications (VBA) and the wire center locations specified as V&H coordinates to compute a set of rings comprising the interoffice network. These ring calculations apply to all operating companies that have at least one tandem.

The interoffice network of rings consists of two ring classes: host/remote and tandem/host/standalone. If the user invokes the feature that allows hosts and remotes to be specified, host/remote rings are used to interconnect remote switches to their serving host. Tandem/host/standalone rings interconnect hosts and standalone wire centers to their serving tandem. The methodology that the Model uses to determine the rings is the same for both classes of rings, with hosts serving as the homing point in the network of hosts, remotes and tandems serving as the homing point in the network of tandems, hosts, and standalone wire centers. Any discussion in the following section is applicable to both the host/remote and tandem/host/standalone classes, unless otherwise noted.

The interoffice distance calculations in HM 5.0a are considerably more sophisticated than earlier versions of the Hatfield/HAI Model.[64] To compute the set of interoffice rings, the HM begins with a case where all wire centers are directly connected to their serving tandem via redundant paths. Each wire center is then examined to determine whether it is more advantageous to leave the wire center directly connected to the tandem or incorporate it into a ring. To make this determination, the HM compares the investment associated with directly connecting the wire center to the tandem with the investment

[64] See Appendix D for a fuller description of these calculations.

associated with placing the wire center on a ring. For direct connections, the investment is a function of the distance from the wire center to the tandem. When determining the investment that is required to add a wire center to a ring, the distance between interconnected wire centers and the additional cost of multiplexing are considered. If the investment on the ring is less than the investment associated with directly connecting to the tandem, the office will be placed on the ring.

The HM 5.0a incorporates an optimizing algorithm to ensure that it constructs rings in an efficient fashion. The savings that are generated by placing a wire center on a ring are computed as the difference between on-ring and directly connected investment. The HM places the offices that produce the greatest savings on the ring first. When no more savings are possible, the process of creating rings is complete.

When computing rings, the greatest savings often is realized by allowing a set of wire centers to form their own standalone ring that does not include the serving tandem as a node. The algorithm requires the tandem to be placed on at least one ring. But since all wire centers must have a communications path to their serving tandem, standalone rings are connected to the tandem through a series of ring connectors that provide paths either between rings, or between a standalone ring and the tandem. The location of each ring connector is determined by identifying the smallest distance from each node on the standalone ring to either the tandem itself, or to any other ring that has tandem connectivity. All ring connector distances and connector terminal costs are doubled to reflect the installation of redundant facilities.

Since rings are interconnected, traffic between wire centers on two rings may "transit" one or more additional rings. Thus, the calculated capacity of a ring, based on the traffic originating/terminating in wire centers on the ring, must be increased to reflect the requirement that the ring also be able to handle transiting traffic. The actual amount of such transiting traffic on a ring is highly dependent on (1) the position of that ring in the overall configuration of rings serving a given area; and (2) the amount of traffic generated (or terminated) by wire centers on a given ring that is destined for wire centers on another ring, and therefore "leaks" out of the originating ring. The model increases the capacity of each ring to handle transiting traffic based on a user-adjustable "transiting factor," whose default value is 0.4. This factor represents the percentage of additional ring capacity consumed by transiting traffic. Thus; the model increases the calculated ring capacity requirement by (1 + transiting factor).

There are two user-adjustable parameters that govern the creation of rings. First, it is possible to set the maximum number of wire centers that may share the same ring – see parameter B142 in Appendix B. The default number is 16. Once this limit has been reached, no additional wire centers will be absorbed by the maximally sized ring – even if doing so would produce a network with a smaller total investment. The second, which applies only to host/standalone/tandem rings, is a threshold value dictating the minimum number of switched plus special lines a wire center must serve to be eligible to be placed on a ring. This threshold corresponds to Parameter B139 in Appendix B; its default value is one.

Wire centers that serve fewer than this threshold total line count will either: 1) directly connect to the tandem; or 2) connect to the nearest standalone or host wire center that is on a ring. The option that yields the shortest spur distance is selected. In either case, redundant facilities are provided.

At the highest level in the ring network, the HM must provide a path for tandem to tandem traffic for tandems that are located in the same LATA. This is accomplished through the use of inter-ring-system connectors.[65] The inter-ring-system connectors facilitate a fully interconnected mesh of all the ring systems that exist within a LATA. Ring systems may be connected to other ring systems either through direct tandem to tandem paths, or through any of the on-ring nodes served by those tandems. Inter-ring-system connectors always follow route-diverse paths and will, in most cases, terminate at unique nodes within each of the ring systems. The nodes and paths selected are those that produce the shortest two paths between ring systems. . To ensure tandem switches are sized to handle inter-tandem traffic, there is a user-adjustable parameter (default value 0.10), identified in Appendix B as "Intertandem Fraction of Tandem Trunks," and expressed as a multiplier of the number of tandem trunks calculated from traffic volumes, that increases the calculated capacity of the tandem switches.

The result of the ring-calculating process is a list of the computed host/remote and tandem/host/standalone ring configurations. These ring configurations are broken out by each tandem or host, and the wire centers they serve through the ring network. The following information is reported in the workfile "ring_io" worksheet for each set of rings: 1) the set of wire centers that comprise the ring; 2) the identification of each wire center and the nodes (other wire centers) to which it connects; 3) the distance between each wire center and the nodes to which it connects; 4) a list of the wire centers served by spurs and their associated spur distance; 5) a list of the wire centers that serve as inter-ring-system connector nodes and their associated inter-ring-system connector distance; and 6) a list of the wire center pairs that serve as ring connectors and the their associated ring connector distances. In addition to the ring distance associated with each wire center, several ring parameters are aggregated by company. These include: 1) the total number of ring connectors; 2) the total ring connector distance; 3) the total number of inter-ring-system connectors; 4) the total inter-ring-system connector distance; and 5) the total number of rings that include the tandem as a node. The model equips each ring connector with the maximum rate SONET equipment (OC-48) in current common use by the LECs. Spur terminals operate at OC-3, a sufficient capacity given the 5000 line threshold for the smaller wire centers being placed on a spur.

Once the model determines the total interoffice distances, considering rings, connectors, and point-to-point links for small offices, it calculates the costs of installed cable and structure based on user-definable inputs for cable costs, structure costs and configurations (e.g., pullbox spacing), the mix of different structure types, and the amount of structure sharing between interoffice and feeder plant. To account for this structure sharing, the model determines the smaller of the investment in feeder and the investment in

[65] A ring system is defined as the set of nodes, connectors, spurs, and ring connectors associated with a particular tandem.

interoffice facilities, and applies the user-specified sharing percentage to the smaller value to calculate the amount of shared structure investment. The model then subtracts this amount of investment from both the interoffice and feeder investment, and reassigns it back to feeder and interoffice according to the relative amounts of investment in feeder versus interoffice. It does this separately for underground, buried, and aerial structure.

Interexchange access facilities require additional treatment. Because interexchange carrier POPs are typically not located on LEC fiber rings, dedicated entrance facilities must be engineered. It is not possible to compute the route miles between wire centers (or tandems) and IXC POPs to size the lengths of these entrance facilities, because in general the locations of IXC POPs are not publicly available. Therefore, the number of POPs per tandem, and the average entrance facility distance, are user-adjustable, with default values of 5 and 0.5 miles, respectively.

6.5.3.3. Tandem Switch Investments

Tandem and operator tandem switching investments are computed according to assumptions contained in an AT&T cost study.[66] The investment calculation assigns a price for switch "common equipment," switching matrix and control structure, and adds to these amounts the investment in trunk interfaces. The numbers of trunks and their related investments, are derived from the transport calculations described above.

The module scales the investment in tandem switch common equipment according to the total number of tandem trunks computed for the study area. By doing so, it avoids equipping maximum-capacity tandems whenever a LATA is served by multiple tandems. The calculations also recognize that a significant fraction of tandems are "Class 4/5" offices that serve both tandem and end office functions. The amount of sharing assumed is user-adjustable, with a default value of 40%. Tandem wire center calculations assume the maximum switch room size, and further assume the tandem will reside in a wire center that contains at least one end office switch.

6.5.3.4. Signaling Network Investments

The Module computes signaling link investment for STP to end office to or tandem "A links," "C links" between the STPs in a mated pair, and "D link" segments connecting the STPs of different carrier's networks. All links are assumed to be carried on the interoffice rings.

The model always equips at least two signaling links per switch. It also computes required SS7 message traffic according to the call type and traffic assumptions described earlier. User inputs define the number and length of ISDN User Part ("ISUP") messages required to set up interoffice calls. Default values are six messages per interoffice call attempt to set up, with twenty-five octets per message.

[66] AT&T, "An Updated Study of AT&T's Competitors' Capacity to Absorb Rapid Demand Growth," filed with the FCC in CC Docket No. 79-252, April 24, 1995, and its predecessor, "A Study of AT&T's Competitors' Capacity to Absorb Rapid Demand Growth," June 20, 1990. ("AT&T Capacity Cost Study").

Other inputs define the number and length of Transaction Capabilities Application Part ("TCAP") messages required for database lookups, along with the percentage of calls requiring TCAP message generation. Default values, obtained from the AT&T Capacity Cost Study, are two messages per transaction, at 100 octets per message, and 10% of all calls requiring TCAP generation. If the message traffic from a given switch exceeds the link capacity (also user-adjustable and set at 56 kbps and 40% occupancy as default values), the model will add links to carry the computed message load. The total link distance calculation includes all the links required by a given switch.

STP capacity is expressed as the total number of signaling links each STP in a mated pair can terminate (default value is 720 with an 80% fill factor). The maximum investment per STP pair is set at $5 million, and may be changed by the user. These default values derive from the AT&T Capacity Cost Study. The STP calculation scales this investment based on the number of links the model requires to be engineered for the study area.

SCP investment is expressed in terms of dollars of investment per transaction per second. The transaction calculation is based on the fraction of calls requiring TCAP message generation. The total TCAP message rate in each LATA is then used to determine the total SCP investment. The default SCP investment is $20,000 per transaction per second, based on a number reported in the AT&T Capacity Cost Study.

6.5.3.5. Operator Systems Investments

Operator tandem and trunk requirements are based on the operator traffic fraction inserted by the user into the model and on the overall maximum trunk occupancy value of 27.5 CCS discussed above. Operator tandem investment assumptions are the same as for local tandems.

Operator positions are assumed to be based on current workstation technology. The default operator position investment is $6,400. The Model includes assumptions for maximum operator "occupancy" expressed in CCS. The default assumption is that each position supports 32 CCS of traffic in the busy hour. Also, because many operator services traditionally handled by human operators may now be served by announcement sets and voice response systems, the model includes a "human intervention" factor that reflects the fraction of calls that require human operator assistance. The default factor is 10, which is believed to be a conservative estimate. (A factor of 10 implies that one out of ten calls will require human intervention).

6.6. Expense Modules

6.6.1. Overview

HM 5.0a contains four Expense Modules in order to allow the user to display results by line density range, by wire center, by CBG or by cluster.[67] Each of the Expense Modules

[67] Although the HM 5.0a engineers no plant based on CBG granularity, the results of its engineering to individual clusters may be rolled up to display cost results at the CBG level.

receive from the other modules all the network investments, by type of network component necessary to provide UNEs, basic universal service and network interconnection and carrier access in each study area. The Expense Modules estimate the capital carrying costs associated with the investments as well as the costs of operating this network. Capital carrying costs include depreciation, return on the debt and equity investment required to build the network and a gross-up to pay for the income taxes imposed on equity returns. Network-related operating expenses include maintenance and network operations. Non-network-related operating expenses include customer operations expenses, general support expenses, other taxes, uncollectibles and variable overhead expenses.

The Expense modules require a number of user inputs. These inputs, and their corresponding default values, appear as inputs B178-B196 in Appendix B.

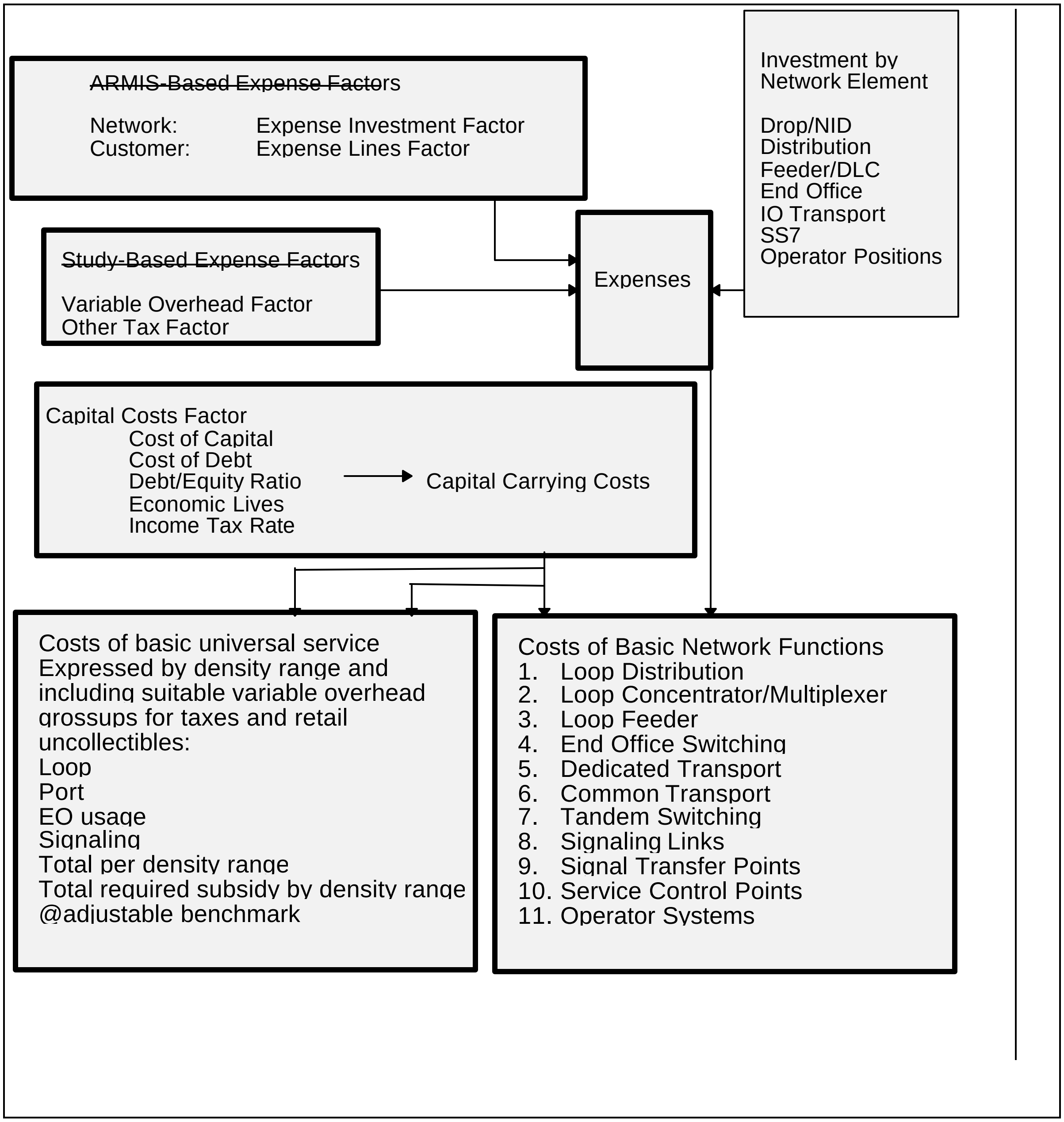

Figure 10 Expense Module Flows

6.6.2. Capital Carrying Costs

Estimating forward-looking capital carrying costs is relatively straight-forward. The FCC and state regulators have developed standard practices that are based on sound economics to perform this function. The model calculates annual capital cost for each UNE component based on:

a) Plant investment for that component from the relevant investment modules,

b) The return to the net asset;

c) An income tax gross-up on the equity component of the return, and

d) The expected service life adjusted for net salvage value (depreciation) of the component.

Each of these elements of the capital carrying cost estimate is discussed below.

The weighted average cost of capital (return) is built up from several components. A 45/55 debt/equity ratio is assumed, with a cost of debt of 7.7 percent and a cost of equity of 11.9 percent, for an overall weighted average cost of capital of 10.01 percent.[68] The equity component of the return is subject to federal, state and local income tax. As a consequence, it is necessary to increase the pre-tax return dollars, so that the after-tax return is equal to the assumed cost of capital. A user-adjustable assumed combined 39.25 percent federal, state and local income tax ("FSLIT") rate is used "gross up" return dollars to achieve this result.

The model assumes straight-line depreciation and calculates return on investment, tax gross-up and depreciation expenses annually on the mid-year value of the investment. Because capital carrying costs are levelized, substitution of nonlinear or accelerated depreciation schedules for straight-line depreciation would have only a modest net effect on calculated annual capital carrying costs (aside from favorable tax effects). Default values for the service lives of the 23 categories of equipment used in the Model are based on their average projection lives adjusted for net salvage value as determined by the three-way meetings (FCC, State Commission, LEC) for 76 LEC study areas including all of the RBOCs, SNET, Cincinnati Bell, and numerous GTE and United companies. The table below shows the plant categories, their economic lives, their percent net salvage value, and the resulting adjusted projection lives upon which depreciation is based. These economic lives and net salvage percents are user-adjustable.

[68] This assumed cost of capital is conservatively high. Current financial analyses show LEC cost of capital to range between 9 and 10 percent. See, AT&T ex parte filing of February 12, 1997, "Estimating the Cost of Capital of Local Telephone Companies for the Provision of Network Elements," by Bradford Cornell, September, 1996.

Account	USOA Category	Economic Lives	Net Salvage Percent	Adjusted Projection Lives
2112	Motor Vehicles	8.24	0.1121	9.28
2115	Garage Work Equipment	12.22	-0.1071	11.04
2116	Other Work Equipment	13.04	0.0321	13.47
2121	Buildings	46.93	0.0187	47.82
2122	Furniture	15.92	0.0688	17.10
2123.1	Office Support Equipment	10.78	0.0691	11.58
2123.2	Company Comm Equipment	7.40	0.0376	7.69
2124	Computers	6.12	0.0373	6.36
2212	Digital Switching	16.17	0.0297	16.66
2220	Operator Systems	9.41	-0.0082	9.33
2232.2	Digital Circuit Equipment	10.24	-0.0169	10.07
2351	Public Telephone	7.60	0.0797	8.26
	NID, SAI			19.29
2411	Poles	30.25	-0.8998	15.92
2421-m	Aerial Cable - Metallic	20.61	-0.2303	16.75
2421-nm	Aerial Cable - Non-Metallic	26.14	-0.1753	22.24
2422-m	Underground - Metallic	25.00	-0.1826	21.14
2422-nm	Underground - Non-Metallic	26.45	-0.1458	23.08
2423-m	Buried - Metallic	21.57	-0.0839	19.90
2423-nm	Buried - Non-Metallic	25.91	-0.0858	23.86
2426-m	Intrabuilding - Metallic	18.18	-0.1574	15.71
2426-nm	Intrabuilding - Non-Metallic	26.11	-0.1052	23.62
2441	Conduit Systems	56.19	-0.1034	50.92
	Average Metallic Cable (calculated)			19.29

Return is earned only on net capital, but because depreciation results in a declining value of plant in each year, the return amount declines over the service life of the plant. To ensure that a meaningful long run capital carrying cost is calculated, the return amount is levelized over the assumed life of the investment using net present value factors. An annual capital carrying charge factor is developed for economic depreciation lives from 1 to 80 years. (*see*, "CCCFactor" worksheet in the Expense Module). These factors (which are also disaggregated into their depreciation, return and tax components) are then applied to investment in each plant category (with interpolation to account for fractional year values for economic life) to determine the annual capital carrying cost for each plant category.

6.6.3. Operating Expenses

Estimating LEC operating costs is more difficult than estimating capital costs. Few publicly available forward-looking cost studies are available from the ILECs. Consequently, many of the operating cost estimates developed here must rely on relationships to and within historical ILEC cost information as a point of departure for estimating forward-looking operating costs. While certain of these costs are closely linked to the number of lines provided by the ILEC, other categories of operating expenses are related more closely to the levels of their related investments. For this reason, the Expense Module develops factors for numerous expense categories and applies these factors both against investment levels and demand quantities (as appropriate) generated by previous modules.

The HM 5.0a density zone Expense Module now includes a USOA Detail worksheet that breaks out the HM 5.0a investments and expense results by Part 32 account for comparison with embedded ARMIS data. There is also an Expense Assignment worksheet that allows the user to vary the proportion of total expenses that are assigned to loop network elements (i.e., NID, distribution, concentration and feeder) based on relative number of lines versus based on the relative amount of direct expenses (direct expenses include maintenance expenses and capital carrying costs for specific network elements).

The operating expenses can be divided into two categories -- network related and non-network related. Network-related expenses include the cost of operating and maintaining the network, while non-network expenses include customer operations and variable overhead.

The cost categories contained in the FCC's USOA are used as the point of departure for estimating the operating expenses associated with providing UNEs, basic universal service and carrier access and interconnection. The major expense categories in the USOA are Plant Specific Operations Expense, Plant Non-Specific Operations Expense, Customer Operations Expense and Corporate Operations Expense. The first two are network-related, the latter are not.

LECs report historical expense information for each of these major categories through the FCC's ARMIS program. The ARMIS data used in the Expense Module include investment and operating expenses and revenues for a given local carrier and state. As noted above, forward-looking expense information for these categories is not publicly available from the ILECs. A variety of approaches are used to estimate the forward-looking expenses.

6.6.3.1. Network-Related Expenses

The two major categories under which network-related expenses are reported by the ILECs are plant-specific operations expenses and non plant-specific operations expenses. The plant-specific expenses are primarily maintenance expenses. Certain expenses, particularly those for network maintenance, are functions of their associated capital investments. The Expense Module estimates these from historic expense ratios calculated from balance sheet and expense account information reported in each carrier's ARMIS report. These expense ratios are applied to the investments developed by the Distribution, Feeder, and Switching and Interoffice Modules to derive associated operating expense amounts. The ARMIS information used to perform these functions is contained in the "ARMIS Inputs" worksheet, and the expense factors are computed in the "'96 Actuals" worksheet of the Expense Module.

Other expenses, such as network operations, vary more directly with the number of lines provisioned by the ILEC rather than its capital investment. Thus, expenses for these elements are calculated in proportion to the number of access lines supported.

The Expense Module estimates direct network-related expenses for all of the UNEs. These operating expenses are added to the annual capital carrying cost to determine the total expenses associated with each UNE. Each network-related expense is described below:

a) *Network Support* -- This category includes the expenses associated with motor vehicles, aircraft, special purpose vehicles, garage and other work equipment.

b) *Central Office Switching* -- This includes end office and tandem switching as well as equipment expenses.

c) *Central Office Transmission* -- This includes circuit equipment expenses applied to transport investment.

d) *Cable and Wire* -- This category includes expenses associated with poles, aerial cable, underground/buried cable and conduit systems. This expense varies directly with capital investment.

e) *Network Operations* -- The Network Operations category includes power, provisioning, engineering and network administration expenses.

The Expense Module uses specific forward-looking expense factors for digital switching and for central office transmission equipment; these values derive from a New England Telephone cost study.[69] The Module similarly computes a forward-looking Network Operations value based on the corresponding ARMIS value. The total Network Operations expense is strongly line-dependent. The model thus computes this expense as a per-line additive value based on the reported total Network Operations expense divided by the number of access lines and deducting a user-adjustable 50 percent of the resulting quotient to produce a forward-looking estimate.

6.6.3.2. NonNetwork-Related Expenses

The Expense Module assigns non-network related expenses to each density range, census block group, or wire center (depending on the unit of analysis chosen) based on the proportion of direct expenses (network expenses and capital carrying costs) for that unit of analysis to total expenses in each category. Each of these expenses is described below:

[69] New England Telephone, 1993 New Hampshire Incremental Cost Study, Provided in Compliance with New Hampshire Public Utility Commission Order Number 20, 082, Docket 89-010/85-185, March 11, 1991.

a) *Variable support* -- Certain costs that vary with the size of the firm, and therefore do not meet the economic definition of a pure overhead, are often included under the classification of General and Administrative expenses by ILECs. For example, if a LEC did not provide loops, it would be a much smaller company, and would therefore have lower overhead costs. Some of these costs are nonetheless attributed to overhead under current ILEC accounting procedures. Therefore, the model includes a portion of these "overhead" costs in the TSLRIC estimates.

   Such variable support expenses for LECs currently are substantially higher than those of similar service industries operating in more competitive environments. Based on studies of these variable support expenses in competitive industries such as the interexchange industry, the model applies a conservative, user-adjustable 10.4 percent variable support factor to the total costs (i.e., capital costs, network-related operations expenses and non-network-related operating expenses) estimated for unbundled network elements, as well as basic local service.

b) *General Support Equipment* -- The module calculates investments for furniture, office equipment, general purpose computers, buildings, motor vehicles, garage work equipment, and other work equipment. The Model uses actual 1996 company investments to determine the ratio of investments in the above categories to total investment. The ratio is then multiplied by the network investment estimated by the Model to produce the investment in general support equipment. The recurring costs -- capital carrying costs and operating expenses -- of these items are then calculated from the investments in the same fashion as the recurring costs for other network components. A portion of general support costs is assigned to customer operations and corporate operations according to the proportion of operating expense in these categories to total operating expense reported in the ARMIS data. The remainder of costs is then assigned directly to UNEs.

c) *Uncollectible Revenues* -- Revenues are used to calculate the uncollectibles factor. This factor is a ratio of uncollectibles expense to adjusted net revenue. The Module computes both retail and wholesale uncollectibles factors, with the retail factor applied to basic local telephone service monthly costs and the wholesale factor used in the calculation of UNE costs.

6.6.4. Expense Module Output

The Density Zone and Wire Center expense modules display results in a series of reports which depict detailed investments and expenses for each UNE for each density zone and wire center, summarized investments and expenses for all UNEs, unit costs by UNE and total annual and monthly network costs. In addition, the UNEs are used to estimate interexchange access costs. The Density Zone, Wire Center, CBG and Cluster expense modules also calculate the cost of basic local service and universal service support across density zones, wire centers, CBGs and clusters, respectively.

6.6.4.1. UNE Outputs (Unit Cost Sheet)

The HAI Model produces cost estimates for Unbundled Network Elements that are the building blocks for all network services. The UNEs are described below.

a) *Network Interface Device* -- This is the equipment used to terminate a line at a subscriber's premise. It contains connector blocks and over-voltage protection.

b) *Loop Distribution* -- The individual communications channel to the customer premises originating at the SAI and terminating at the customer's premises. In the HAI Model, this UNE also includes the investments in NID, drop and terminal/splice, and for long loops, the cost of T1 electronics.

c) *Loop Concentrator/Multiplexer* -- The DLC remote terminal at which individual subscriber traffic is multiplexed and connected to loop distribution for termination at the customer's premises. The HAI Model includes DLC equipment and SAI investment in this UNE.

d) *Loop Feeder* -- The facilities on which subscriber traffic is carried from the line side of the end office switch to the Loop Concentration facility. The UNE includes copper feeder and fiber feeder cable, plus associated structure investments (poles, conduit, etc.)

e) *End Office Switching* -- The facility connecting lines to lines or lines to trunks. The end office represents the first point of switching. As modeled in the HAI Model, this UNE includes the end office switching machine investments and associated wire center costs, including distributing frames, power and land and building investments.

f) *Operator Systems* -- The systems that process and record special toll calls, public telephone toll calls and other types of calls requiring operator assistance, as well as Directory Assistance. The investments identified in the HAI Model for the Operator Systems UNE include the operator position equipment, operator tandem (including required subscriber databases), wire center and operator trunks.

g) *Common Transport* -- A switched trunk between two switching systems on which traffic is commingled to include LEC traffic as well as traffic to and from multiple IXCs. These trunks connect end offices to tandem switches. Results are provided on a per-minute basis for the central office terminating equipment associated with the UNE, and for the transmission medium.

h) *Dedicated Transport* -- The full-period, bandwidth-specific interoffice transmission path between LEC wire centers and an IXC POP (or other off-network location). It provides the ability to send individual and/or multiplexed switched and special services circuits between switches. Results are provided on a per-minute basis and per-channel basis for the central office terminating equipment and entrance facilities associated with the UNE, and on a per-minute and per-channel basis for the transmission medium.

i) *Direct Transport* -- A switched trunk between two LEC end offices. Results are provided on a per-minute basis for the central office terminating equipment associated with the UNE, and on a per-minute basis for the transmission medium.

j) *Tandem Switching* -- The facility that provides the function of connecting trunks to trunks for the purpose of completing inter-switch calls. Similar types of investments as are included in the End Office Switching UNE are also reflected in the Tandem Switching UNE.

k) *Signaling Links* -- Transmission facilities in a signaling network that carry all out-of-band signaling traffic between end office and tandem switches and STPs, between STPs, and between STPs and SCPs. Signaling link investment is developed by the HAI Model and assigned to this UNE.

l) *Signal Transfer Point* -- This facility provides the function of routing TCAP and ISUP messages between network nodes (end offices, tandems and SCPs). The Model estimates STP investment and assigns it to this UNE.

m) *Service Control Point* -- The node in the signaling network to which requests for service handling information (*e.g.*, translations for local number portability) are directed and processed. The SCP contains service logic and customer specific information required to process individual requests. Estimated SCP investment is assigned to this UNE.

6.6.4.2. Universal Service Fund Outputs (USF Sheet)

The calculation of costs for basic local service is based on the costs of the UNEs constituting this service. These are the loop, switch line port, local minute portions of end office and tandem switching, transport facilities for local traffic, and the local portions of signaling costs.[70] In addition, costs associated with retail uncollectibles, variable overheads, and certain other expenses required for basic local service, such as billing and bill inquiry, directory listings, and number portability costs, are included. No operator services or SCP costs are included. The model user has the ability to select dynamically the portions of non-traffic-sensitive UNEs to be included in the supported basic local service.

The USF report in the expense module then compares the monthly cost per line used at residence or business intensity in each density range, wire center, CBG or cluster to user-adjustable “benchmark” monthly costs for local service (which includes the End User Common Line charge). If the cost exceeds the associated benchmark, the model accumulates the total required annual support relative to stated benchmarks according to the number of primary residence lines, secondary residence lines, single line business lines, multiline business lines, or public lines by density zone, wire center, CBG or cluster (depending on the unit of analysis selected).

[70] On an optional basis, the usage sensitive cost of switched access use can be included as well.

The Density Zone USF sheet now contains separate state and federal fund calculations. These permit separate state and federal cost benchmarks; as well as the opportunity to separately specify the particular services (e.g., primary and secondary residential lines, single line business, etc.) to be supported.

6.6.4.3. Carrier Access and Interconnection (Cost Detail Sheet)

The calculation of the costs for carrier access and interconnection to the ILEC's local network are displayed in the "Cost Detail" sheet of the expense module. These costs are built up from the costs of the UNEs that constitute them. In particular, the costs of IXC switched access and local interconnection are based simply on the unit costs of EO switching, dedicated transport, common transport, tandem switching and ISUP signaling messages. In addition, the sheet also displays built up costs of various signaling services that might be used by IXCs or CLECs, as well as the costs of several forms of dedicated transport.

7. Summary

In its Release 5.0a formulation, the HAI Model reliably and consistently estimates the forward-looking economic cost of unbundled local exchange network elements, carrier access and interconnection and the forward-looking economic cost of basic local telephone service for universal service funding purposes. It uses the most accurate and granular data on actual customer locations available today, and it overlays its loop distribution network on these actual customer locations.

Because all of these calculations are performed in adherence to TELRIC/TSLRIC principles, HAI Model cost estimates provide the most accurate basis for the efficient pricing of unbundled network elements carrier access and interconnection and the calculation of efficient universal service funding requirements.

Like its predecessor, the HM 5.0a methodology is open to public scrutiny. To the extent possible, it uses public source data for its inputs. When documentable public source data is lacking, these default input values represent the developers' best judgments of efficient, forward-looking engineering and economic practices. In addition, because these inputs are adjustable users of HM 5.0a can use the model's automated interface to model directly and simply any desired alternative.

Appendix A

History of the Hatfield/HAI Model

Appendix B

HM 5.0a Inputs, Assumptions and Default Values

Appendix C

HM 5.0a Input Data Development Flow Charts

Appendix D

General Rules Governing the Creation of the HM 5.0a Distance Files

Appendix E

Equation Listings for the HM 5.0a Network Engineering Logic Modules:

Distribution
Feeder
Switching and Interoffice